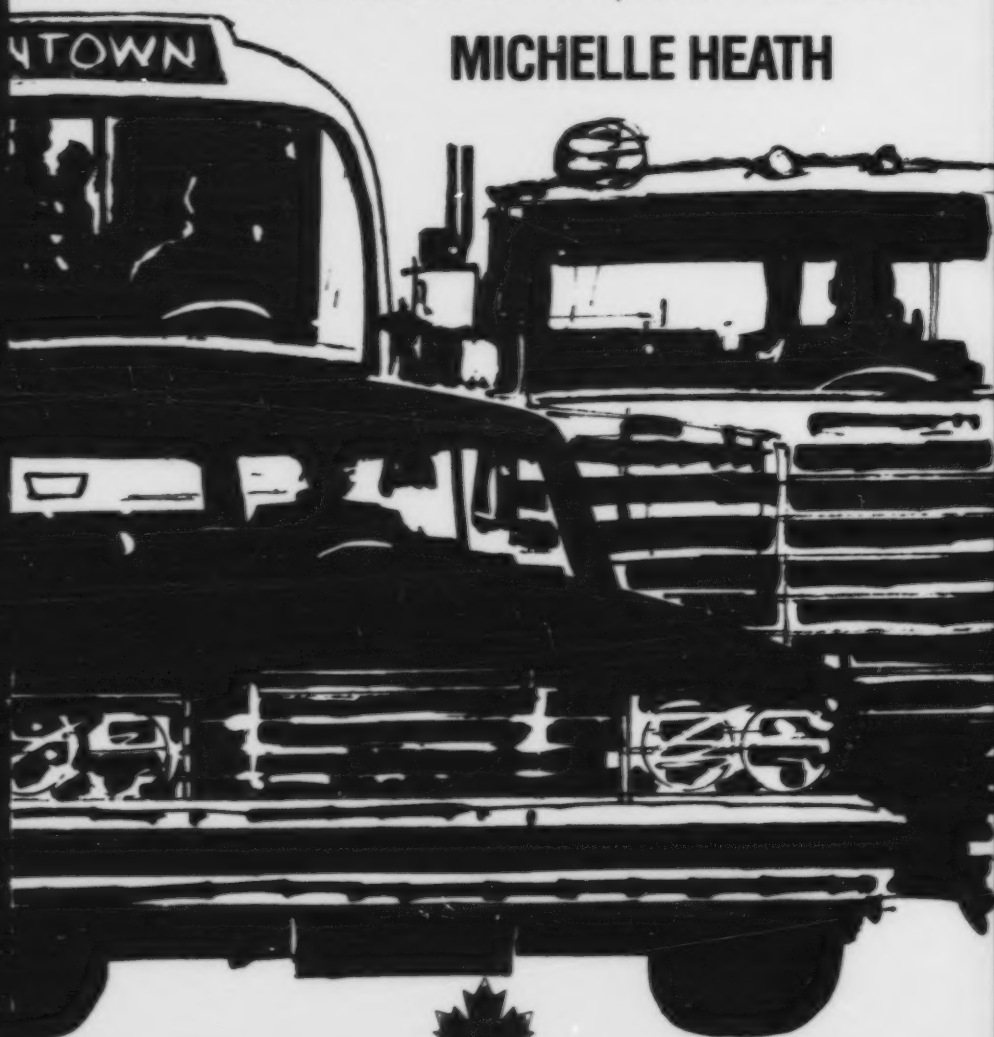


ALTERNATIVE **Transportation Fuels**

NATURAL GAS, PROPANE, METHANOL & ETHANOL compared with GASOLINE & DIESEL

MICHELLE HEATH



STUDY NO. 37, FEBRUARY, 1991, ISBN 0-920522-66-1



CANADIAN ENERGY RESEARCH INSTITUTE

ERRATA

Page 91, Table 3.3

Ford F-150, percent of indolene...23 should be 0.23. The second set of Ford F-150 results are 'first bag' results followed by an addendum of the 'first bag' results from the Chevrolet Silverado.

TABLE 3.3

INDOLENE-PROPANE EMISSIONS COMPARISON, URBAN DYNAMOMETER DRIVING SCHEDULE TEST SERIES AVERAGE COMPOSITE RESULTS

	HC	CO	NO _x	CO ₂	°C Ambient Start-up Temperature
Standard (g/mile)	0.8	10.0	1.7	No Std.	
<u>Ford F-150</u>					
Indolene	1.62	16.80	1.12	579	7.5 (Average of 6 Runs)
Propane	1.20	0.04	0.80	555	3.9 (Average of 14 Runs)
Propane Emissions as a Percent of Indolene	74	0.23	71	95	
<u>Chevrolet Silverado</u>					
Indolene	0.67	10.9	1.1	591	7.7 (Average of 6 Runs)
Propane	0.3	4.67	0.36	561	9.3 (Average of 6 Runs)
Propane Emissions as a Percent of Indolene	44	43	31	95	
<u>Cold Start (UDDS First Bag Results)</u>					
<u>Ford F-150</u>					
Indolene	5.77	78.94	1.78	503	8.1 (Average of 6 Runs)
Propane	1.58	0.28	1.46	595	3.2 (Average of 14 Runs)
Propane Emissions as a Percent of Indolene	27	0.35	82	118	
<u>Chevrolet Silverado</u>					
Indolene	2.77	51.9	1.70	582	7.0 (Average of 6 Runs)
Propane	1.09	20.82	0.80	557	7.8 (Average of 14 Runs)
Propane Emissions as a Percent of Indolene	39	40	46	96	

SOURCE: Charles S. Dempsey, Propane Gas Association of Canada Inc., "Propane Fueled Engines and the Impact of Decreasing Temperatures on Exhaust Emissions - A Year Round Advantage," paper presented at the 1990 Windsor Workshop on Alternative Fuels, Toronto, Ontario, June 11-14, 1990, p. 3.



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**ALTERNATIVE TRANSPORTATION FUELS:
NATURAL GAS, PROPANE, METHANOL & ETHANOL
COMPARED WITH GASOLINE & DIESEL**

MICHELLE HEATH

Alternative Transportation Fuels: Natural Gas,
Propane, Methanol & Ethanol compared with Gasoline & Diesel

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ISBN 0-920522-66-1

Author: Michelle Heath

CANADIAN ENERGY RESEARCH INSTITUTE
3512 - 33RD STREET N.W.
CALGARY, ALBERTA
CANADA T2L 2A6

TELEPHONE: (403) 282-1231

FACSIMILE: (403) 284-4181

February 1991
Printed in Canada

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PREFACE

In early 1990, a study was undertaken in cooperation with Energy, Mines and Resources Canada to examine and compare the usefulness of natural gas, propane, methanol and ethanol in relation to gasoline and diesel fuel for potential use in Canada's transportation industry. The reasons for implementing the study were two-fold. The ongoing political crisis in the Middle East, which contains the largest supplies of conventional oil in the world, imposes both supply constraints and crude price fluctuations catalysing the concern for security of inexpensive oil supplies and transportation fuels. As well, environmental concerns such as the greenhouse effect, the carbon monoxide issue and the ozone problems are under increasing scrutiny in this energy intensive industrialized nation.

The Green Plan recently released by the Government of Canada suggests that in the short term, improvements in energy efficiency will provide the greatest decrease in the volume of pollutants being emitted into the atmosphere each year. However, as the consumption of fossil fuels is the primary source of carbon dioxide, the major greenhouse gas, the long term goal of reducing greenhouse gas emissions will depend upon our ability to move to less carbon-intensive energy sources. With these concerns in mind, this study focussed on evaluating the potential environmental and economic benefits to Canada of each of the fuels examined.

The author wishes to express her gratitude to those technical experts at Energy, Mines and Resources Canada who provided direction in the course of this study. Special thanks is also extended to the many experts in industry who shared of their knowledge.

The author is indebted to a number of colleagues at the Institute who provided assistance at various stages of the project. Particular thanks to Garth Renne who provided substantial research assistance as well as programming and computer support. The extensive graphics were provided by Megan Murphy while Beverly Kovacs processed the interim drafts and final manuscript. Thanks also to Wendy Faid and Lynne Storey of the I.N. McKinnon Memorial Library who aided in gathering the available resource material from across the continent. Dr. Gerry Angevine and Anthony Reinsch provided support and guidance throughout the project and Nancy Sanford proofed the report.



Chapter 1

NATURAL GAS, PROPANE, METHANOL AND ETHANOL: VIABLE ALTERNATIVE FUELS FOR THE TRANSPORTATION INDUSTRY

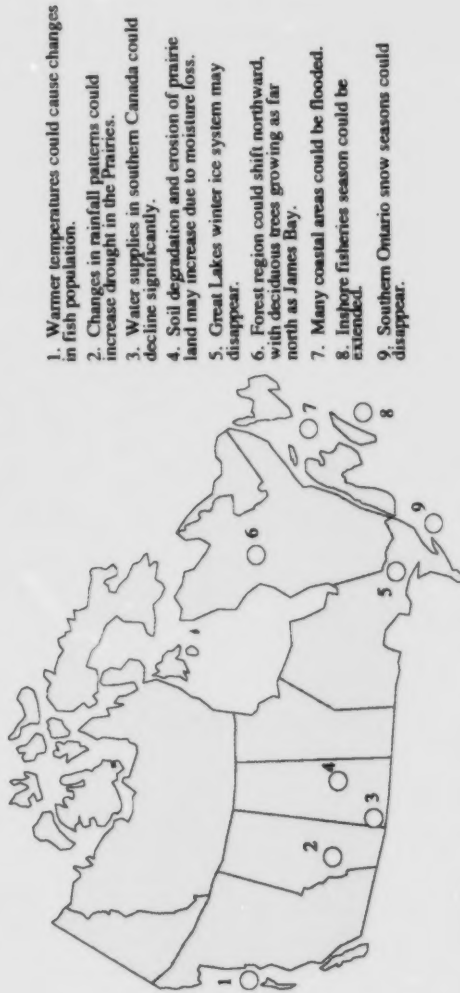
1.1 Present Status of Alternative Fuels in Canada and the Reasons for Current Interest

Canada has a population of 25.5 million people who own and operate 11 million cars and 3 million trucks and buses. Ninety-five percent of the energy requirements of these vehicles are currently met by one of our nation's primary resources--crude oil. But, our relatively inexpensive conventional oil supplies are being steadily depleted, while at the same time being subject to increasing demand. Although there is no question in the minds of Canada's policy makers that gasoline and diesel fuel will maintain the leading positions in the transportation fuel market, declining conventional crude oil reserves, volatile oil prices, and the ever growing concern for clean air have brought to the forefront the potential for use of natural gas, propane, methanol and ethanol by Canada's transportation sector as strategic alternatives to the currently available liquid fuels.

Stringent new diesel standards legislated to take effect in 1991, as well as other clean air development strategies, are requiring the petroleum industry and the automobile manufacturers to react. Automotive emission standards are changing as vehicle emissions have been identified as the major source of air pollution. Canadians are demanding not only a lead-free fuel environment but fuel types which will reduce the amounts of carbon dioxide (CO_2), nitrogen oxide (NO_x), carbon monoxide (CO) and particulates being released into our atmosphere. The potential impacts of the greenhouse effect (see Figure 1.1), the carbon monoxide issue and the ozone problem are all under increasing scrutiny.

The fuel efficiency of road transportation vehicles has improved significantly over the past decade with enhancements to both engines and vehicle design. Yet, traffic congestion and its environmental consequences are growing concerns, particularly in urban centres. The surging demands on transportation fuels to ensure

Figure 1.1
Impacts of Global Warming on Canada



SOURCE: Canada's Green Plan.

environmental quality and energy conservation while meeting safety requirements, have resulted in refiners reformulating gasoline and diesel fuels as well as increased research into the potential economic and environmental value of alternative gaseous fuels, alcohol fuels, hydrogen and electric-fuelled vehicles. Canadian policy makers continue exploring for methods of retarding the rate of environmental degradation while at the same time striving to maintain self-sufficiency in the oil industry.

With these objectives in mind, this study examines and compares the potential for natural gas, propane, methanol and ethanol in relation to gasoline and diesel fuel in Canada's transportation industry. Since gasoline and diesel prices fluctuate with crude oil prices, the economic analysis performed is directed at determining the per litre equivalent price differential necessary for each of the alternative fuels examined herein to maintain a competitive pricing position in the current market-place (see Figure A.1).

This chapter examines the characteristics necessary for an energy source to qualify as a viable alternative fuel. Chapters 2 through 5 examine each fuel individually—basic characteristics, vehicle conversion options, environmental and safety aspects as well as economic advantages and/or disadvantages. Chapter 6 provides an overview of the current institutional and economic barriers confronting these alternative fuel sources, evaluates each of them based on the characteristic requirements outlined in Chapter 1, and presents a number of conclusions arising from this research program.

In addition to these six chapters, there are nine appendices. Appendix A contains tables showing the physical and chemical characteristics of the fuels and additional tables of importance to the environmental issues examined. Appendix B provides the current and proposed regulations and emissions requirements in the Canadian vehicle fleet. Appendix C outlines the utilization of the fuel alternatives being examined in various foreign countries. Appendices D through H provide additional sensitivities to the economic analysis and Appendix I presents a regional alternative fuel demand analysis.

1.2 Characteristics Necessary to Qualify as Viable Alternative Fuels

The opportunities for natural gas, propane, methanol and ethanol as alternative fuel sources in Canada will ultimately be

determined by their ability to provide for, and meet the demands of, this nation's transportation sector.

Alternative fuels must be environmentally acceptable. There is no question that the current perceived need for alternative fuels is derived from the growing concern for a cleaner, environmentally safe atmosphere.

The use of fossil fuels is considered the single largest anthropogenic source of air pollution in Canada. The production-through-combustion cycle of gasoline and diesel fuel generates large quantities of hydrocarbons (HC), carbon monoxide (CO) and nitrogen oxides (NO_x). As well, the diesel fuel used in compression ignition engines generates large quantities of particulates (see Table A.2). The Canadian consumer, along with the legislators of Canada's energy policies, is becoming increasingly aware of the need to consider the global concern for environmental pollution. Strategies being considered to decrease the emissions produced by fossil fuels include the use of clean burning alternative fuels, such as those being considered in this study.

Declining diesel fuel quality is another issue causing environmental concern. The quality of diesel fuel is decreasing as the sulphur and aromatic content of these fuels increases. The United States Transportation Research Board found the cetane number¹ for diesel fuel dropped four full points over a ten year period, while according to the United States Motor Vehicle Manufacturers Association, the sulphur content rose from 0.19 to 0.31 percent in three years. It has been suggested that the quality and characteristics of the diesel fuels being produced from Canada's syncrude plants are similar to those being marketed in the United States. Therefore, as Canada's crude supplies become more dependent on nonconventional sources, precautionary measures must be taken to ensure environmentally safe upgrading of the associated petroleum products or alternative fuel sources must be developed which can be used as effective substitutes.

Additional environmental issues directly affected by the burning of fossil fuels are the following:

- The "greenhouse" phenomenon is thought to be created when gases such as carbon dioxide (CO₂), methane (CH₄), nitrous oxides (NO_x), chlorofluorocarbons (CFCs), and ozone (O₃) absorb some of the sun's infrared radiation reflected from the earth's surface, trapping it in the atmosphere and reradiating it back to the surface, thus warming the earth. Carbon dioxide is

thought to be the leading cause of the greenhouse effect due to its higher atmospheric concentration even though other greenhouse gases are more efficient at absorbing solar radiation on a molecular basis.²

Greenhouse Gas Contribution to Global Warming

Carbon dioxide - 55%
 Methane - 15%
 CFC-11 and CFC-12 - 17%
 Other CFCs - 7%
 Nitrogen Oxide - 6%³

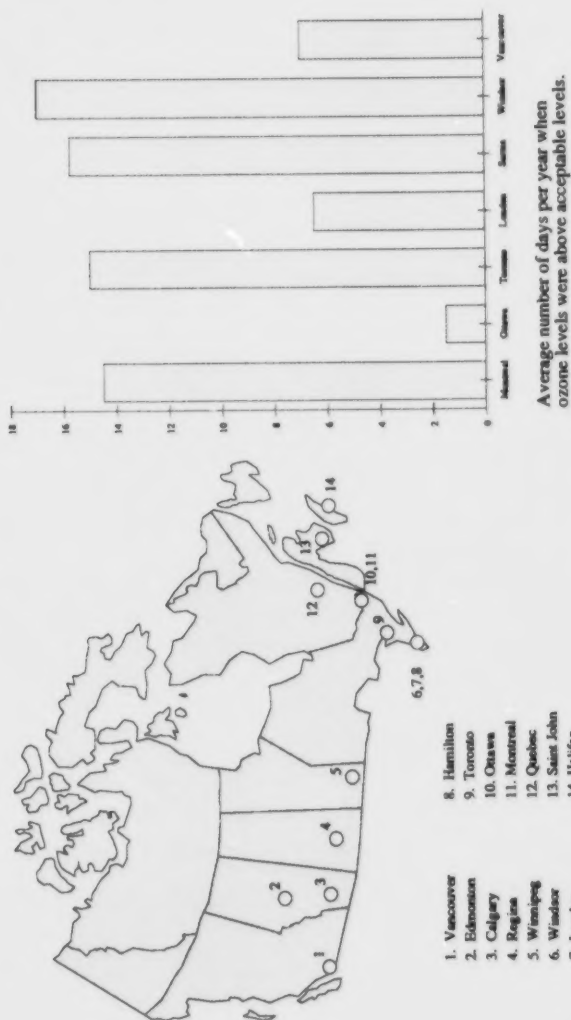
The accumulation of these greenhouse gases, which has increased significantly over the past three decades,⁴ could in fact result in changing precipitation patterns, disruption to the agricultural communities, melting at the polar ice caps and severe flooding. A great many scientists are examining this phenomenon and trying to determine ways of slowing down or eliminating its occurrence (above levels necessary for normal plant growth, etc.) in our atmosphere. Of particular concern are the CO₂ emissions from the production, distribution and use of fossil fuels in our transportation industry which, as noted above, are boosting interest levels for clean burning low-emission alternatives.

- Ozone is a highly reactive form of oxygen which at ground level can aggravate the eyes, nose and respiratory passages as well as damage crops. This gas is formed when nitrogen oxides chemically react with reactive hydrocarbons in the presence of sunlight. Numerous observations indicate increasing tropospheric ozone concentrations.

In Canada, ozone problems occur almost exclusively during the summer. The ozone episodes usually last from one to five days. As the highest levels normally occur in the more highly populated regions (and as most of Canada's population lives in urban centres), it is estimated that over half this country's population is exposed during summer months to ozone levels which can have negative health effects (see Figure 1.2).⁵

- Carbon monoxide, a poisonous gas, is another environmental pollutant. Throughout North America, increasingly high concentrations of CO, attributed to motor vehicles (as a consequence of combustion with insufficient air),⁶ are found in urban centres.
- The carcinogenic effects of aromatics and aldehydes are also a major concern being closely examined today.

Figure 1.2
Areas of Smog Concentrations in Canada



SOURCE: Canada's Green Plan.

Figures A.2, A.3, and A.4 in Appendix A indicate the findings of Environment Canada's 1985 national emissions inventory.

Alternative fuels must be capable of attaining competitive economics within the time frame determined by Canada's declining conventional oil reserves.

There is a growing feeling that the price of the transportation fuels sold in the Canadian market-place should reflect their full social and economic cost. Gasoline and diesel fuels are relatively cheap to produce and the cost of the infrastructure necessary for their distribution is fairly well defined. But, the extraneous costs to the environment and ultimately to our health may, on the other hand, prove very large.

From the consumer's point of view, of course, the most influential consideration affecting decisions of whether or not to convert to an alternative fuel is the potential for cost savings. The overall economics of conversion can be evaluated using the following salient variables:

- the vintage of the vehicle being converted and the condition of its engine;
- the price differential or market value of the fuel in relation to gasoline or diesel fuel;
- the conversion costs;
- the distance travelled annually;
- the type of operation: single vehicle, small commercial fleet, or large commercial fleet, and the compressor or fuelling station costs;
- the volume of fuels being consumed and distillate being displaced;
- incentives and subsidies; and
- the environmental incentives and their costs and benefits to the Canadian citizen.

The full-cycle costs of natural gas, propane, methanol and ethanol may prove fairly expensive in the short term. However, their environmental benefits may be more than offsetting.

Alternative fuels must be capable of providing the necessary octane enhancement.

Lead was eliminated from Canadian gasolines effective December 1990. Lead phaseout and the increasing demand for premium unleaded fuels may well promote the demand for alternative fuels with a higher octane value⁷ than can be provided by the current streams entering the gasoline pool.

Alternative fuels must be capable of being used as fuel substitutes and not just as fuel extenders.

To become economically viable, the alternatives must be capable of substituting for gasoline and/or diesel fuel in order to capture enough of the transportation fuel market to recover the high capital cost involved with establishing themselves as viable fuel sources in an already mature transportation industry.

Alternative fuels must have a plentiful supply source.

Other than gasohol (10 percent ethanol and 90 percent gasoline), which is fairly compatible with the current vehicle fleet, utilization of the three other alternative fuels on a stand alone--or "neat"--basis requires either the design of new engines or the retrofitting of those in use today. The "original equipment manufacturers" (OEMs) would not likely consider retrofitting, let alone investing in the design of new "alternative fuel" engines, unless they were assured their customers were going to be guaranteed a fuel supply source and be satisfied with fuel performance. After all, they have millions of dollars invested in the design of the cars travelling our highways today with one goal in mind--satisfied customers who will ultimately lead to a satisfactory return on that investment.

Alternative fuels must be easily distributable.

In considering the financial constraints involved with establishment of a new fuel in the market, one has to assess all the steps and operations required to produce, refine, market and distribute these fuels. For instance, will the product be capable of utilizing distribution systems currently in existence or will new trucks, barges, tankers and/or pipelines have to be built? Will the gas stations or other fuel distributors be able to utilize the equipment they have on hand or will new storage tanks, fuel hoses, etc., be required? These costs must be assessed and their implications fully analysed before a new fuel enters

the market. After all, it is the consumer who will ultimately carry the extra cost, whether by buying the fuel or purchasing the vehicle.

Alternative fuels must have widely developed and commercial production and vehicle technologies.

Established production technologies must be available if large-scale production capacity is to be guaranteed in the near term. Simultaneously, vehicle utilization technology for cars, trucks and buses must be further researched and developed in order to optimize both fuel efficiency and environmental benefits.

The aforementioned characteristics are the criteria which will be used to determine which of the four alternative fuels being examined and compared in this study can indeed become active participants in the growing and increasingly demanding transportation industry.

Footnotes

¹The cetane rating of a fuel is defined as a measure of its ability, when compressed and heated, to auto-ignite. A compression ignition diesel engine, with no external ignition source, requires a high cetane fuel for proper operation.

²Energy, Mines and Resources Canada, *Energy Use and Atmospheric Change, A Discussion Paper* (Ottawa, Ontario: Efficiency and Alternative Energy Branch, Energy Policy Branch, August 10, 1990), p. 4.

³*Ibid.*, p. 5.

⁴*Ibid.*, p. 4.

⁵Federal/Provincial Long Range Transport of Air Pollutants Steering Committee, "Management Plan for Nitrogen Oxides (NO_x) and Volatile Organic Compounds (VOCs), First Edition, Draft, March 1990, for Stakeholder Consultation, p. 11.

⁶International Energy Agency, *Substitute Fuels for Road Transport, A Technology Assessment* (Paris, France: OECD/IEA, 1990), p. 63.

⁷The octane rating of a fuel is a measure of its ignition characteristics. In particular, it measures a fuel's resistance to knock, a phenomenon resulting from spontaneous combustion apart from the spark-initiated flame front.

Chapter 2

NATURAL GAS

2.1 Introduction

Natural gas is an excellent fuel for transportation as well as one of Canada's most abundant fuel resources. With 2.5 trillion cubic metres of proved natural gas reserves and a potential reserve base in the area of 7 trillion cubic metres, it is understandable why Canada's policy makers and gas producers are promoting interest in natural gas fuel development. Although recent contracts with buyers in the United States have provided new markets for a portion of Canada's natural gas production, the current demand for natural gas, both in the domestic and export markets, remains below production capacity (see Figure 2.1). Indeed, reduced consumption of natural gas, coupled with additions to domestic gas supply, have resulted in what has been termed the "gas bubble". When this supply situation is considered along with the fact that approximately 85 percent of the nation's 14 million vehicles are in areas served by natural gas pipelines, it becomes clear that the use of natural gas by Canada's transportation sector provides both attractive markets and a strategic alternative to currently available liquid fuels.

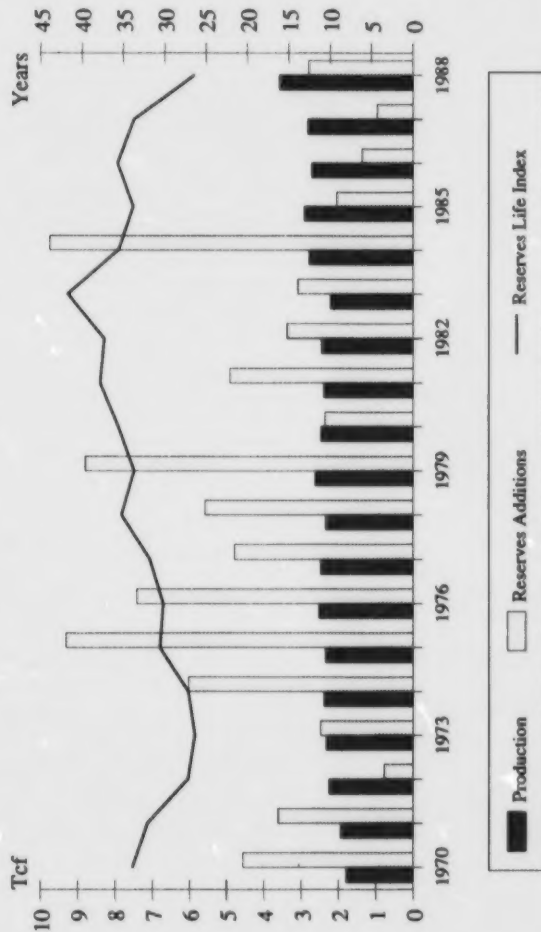
The economic benefits of natural gas for vehicles (NGV) have been the driving force behind marketing efforts in the past. An increasingly apparent and seemingly irreversible concern for environmental deterioration has opened a new and broader window of opportunity for natural gas as a transportation fuel. As one of several cleaner burning fuels which are gaining recognition as alternatives to the current use of gasoline and diesel, natural gas has the potential to benefit from its ability to reduce the emissions of carbon monoxide, reactive hydrocarbons, particulates and nitrogen oxide--the leading causes of urban air quality problems.

2.2 Technical Assessment

2.2.1 Production Technology

Natural gas is produced in its raw state from reservoirs beneath the earth's surface. Although the composition of natural gas varies among wells, it is composed primarily of CH_4 , usually over 85

Figure 2.1
Historical Reserves Replacement
Canadian Natural Gas



SOURCE: Canadian Petroleum Association.

percent. Other substances which may be contained in raw natural gas are water vapour, ethane (C_2H_6), propane (C_3H_8), butane (C_4H_{10}), pentane (C_5H_{12}), hydrogen sulphide (H_2S), nitrogen (N_2), and CO_2 . The majority of these substances are removed at gas processing plants before the gas is transported in a pipeline or utilized in a vehicle (see Figure 2.2). The hydrocarbons ethane, propane, butane and pentane are removed for alternate uses as well as to prevent condensation in the pipelines during the transmission of natural gas. The hydrogen sulphide and carbon dioxide are removed because of their potential to corrode the distribution system. The water vapour is also eliminated to prevent freezing problems which may occur during transmission. Processed natural gas is about 97 percent methane.

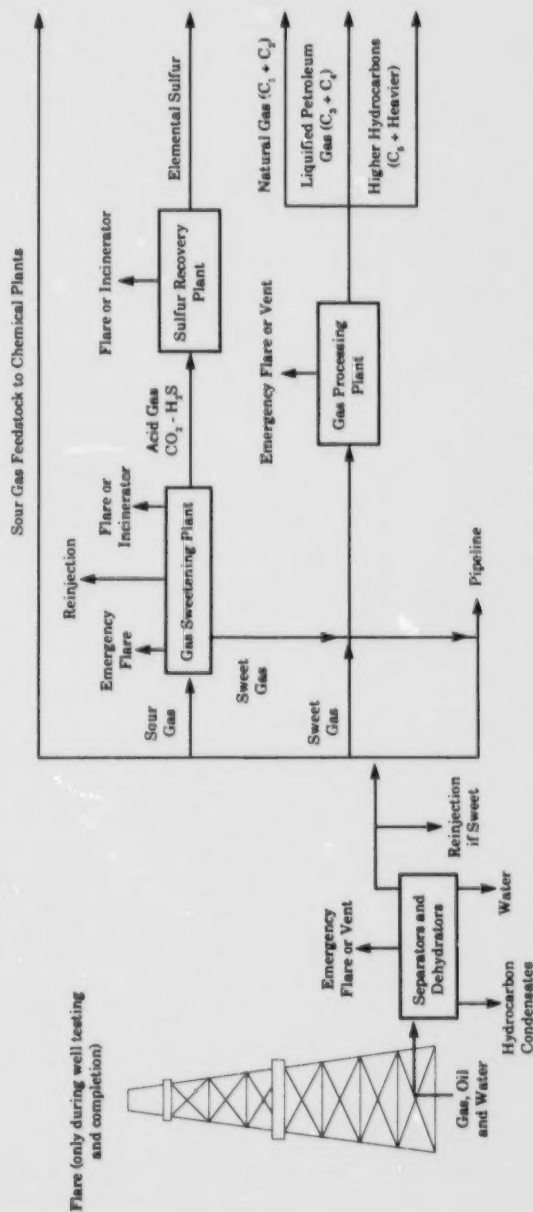
2.2.2 Composition and Characteristics

Natural gas is a hydrocarbon which is colourless, odourless and much lighter than air. It can be used as a transportation fuel in either a compressed state, CNG, or a liquified state, LNG. Compressed natural gas for use as a transportation fuel is generally referred to as NGV. The advantage of LNG over NGV is its much higher energy density, which provides a greater driving range for an equivalent tank size. However, the disadvantages of LNG tend to outweigh its advantages in that it is more difficult and costly to produce as well as to store. Therefore, although LNG is recognized as having potential for use in aircraft, ships and trains which demand greater rates of fuel consumption, it is currently not being given consideration in Canada as an automotive fuel.

Natural gas, as its name suggests, is in a gaseous state at ambient temperatures. The disadvantage to this is that it has a very low energy density unless compressed. In fact, a full tank of gasoline has 930 times the energy content of a full tank of natural gas. To eliminate the bulkiness, natural gas is compressed to pressures varying globally from 2000 to 3600 pounds per square inch. Once compressed, the gas is stored in cylindrical tanks.

NGV has an energy content by weight which is comparable to gasoline and diesel fuel. However, because of the lower storage densities, this fuel has lower energy content (Btu content) per unit volume. Due to the size and weight of the storage tanks that would be necessary to carry natural gas supplies equivalent in Btu content to gasoline, motorists usually resort to having fewer storage cylinders on board their vehicle and refuelling more frequently than they would

Figure 2.2
Flow Diagram of Natural Gas Processing



SOURCE: *Cost-Effectiveness of Alternative Transportation Fuels in Urban Bus Operations*, CANMET.

with gasoline (see Table 2.1). Table A.1 provides the physical properties of natural gas.

2.2.3 Uses as a Petroleum Substitute

Natural gas is utilized extensively as an energy source, providing a good portion of Canada's residential, commercial, and industrial power requirements (see Figure 2.3).

As an up and coming contender in the transportation industry due to plentiful sources of supply, low processing costs and ease of distribution, natural gas is seen as an alternative for gasoline and diesel in internal combustion engines.

2.3 Performance and Compatibility with Current Fuels and the Fuel Distribution System

2.3.1 Compatibility with Current Vehicles

The physical characteristics of natural gas are such that its use requires a variety of modifications to both current vehicle and engine designs, as well as to fuel supply systems.

Natural gas experiences a 10 percent power loss because, as a gaseous fuel, it displaces air in the combustion chamber which could otherwise be used in the combustion process. This power loss combined with possible fuel storage capacity constraints can result in reduced driving ranges in the order of 130 to 325 kilometres (80 to 200 miles).¹ The need for additional storage cylinders is by far the largest problem associated with redesigning current gasoline and diesel vehicles to run on natural gas due to:

- the additional weight;
- the additional space taken up as a result of their size; and
- the additional cost associated with acquiring them.

The drawbacks associated with the installation of natural gas cylinders are most noticeable in passenger cars, where they reduce trunk space and impose a very significant weight penalty. Trucks, buses, and heavy-duty vehicles in general are more likely to be capable

TABLE 2.1
FABER AUTOMOTIVE CYLINDERS

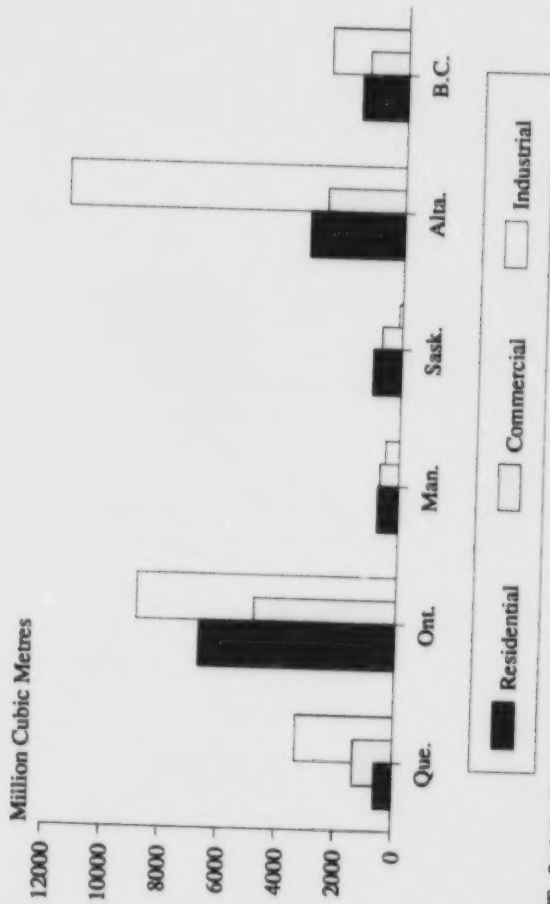
Capacity Water Lt (Imp Gal)	Capacity ^a CNG M ³ (Ft ³)	Equivalence to ^b Gasoline Lt (Imp Gal)	Inside Diameter mm (inch)	Length mm (inch)	Weight of Empty Cylinder kg (lbs)	Weight of Gas/Cylinder kg (lbs)
40 (8.81)	10.12 (347)	12.1 (2.7)	267 (10.51)	900 (35.4)	41 (90)	7.2 (15.8)
50 (11.01)	12.65 (433)	15.1 (3.3)	316 (12.44)	830 (32.67)	51 (112)	9.0 (19.8)
55 (12.11)	13.92 (477)	16.7 (3.7)	316 (12.44)	905 (35.63)	55 (122)	9.1 (21.8)
60 (13.22)	15.18 (520)	18.2 (4.0)	316 (12.44)	980 (38.6)	61 (135)	10.82 (23.8)
70			(12.44)	(43)	(156)	

SOURCE: Canadian Western Natural Gas Co.

^aBased on CNG at 3014.7 psia/70°F.

^bBased on 130 cu.ft./Imp. Gal.

Figure 2.3
Regional Natural Gas Sales
1989



SOURCE: Statistics Canada, Catalogue
No. 55-002, December 1989.

of handling the added space and weight penalties, as their overall load-carrying capacities are reduced by a relatively smaller percentage.

There are, however, some very distinct benefits to using natural gas rather than gasoline in the Canadian vehicle fleet. In contrast to gasoline, natural gas is injected into the engine cylinders in a completely vapourized state, which results in smoother throttle response, minimized spark-plug fouling, easier cold weather starting and reduced engine wear and maintenance.

The octane rating of a fuel, as defined in Chapter 1, measures a fuel's ability to resist spontaneous ignition when fuel and air are combined and then compressed in an engine's combustion chamber. If the fuel's octane number is too low, a knocking or pinging results and a corresponding loss of power is experienced. Natural gas has an octane rating which ranges between 120 and 130, outperforming even premium gasolines containing antiknock additives. This potential for higher compression ratios also results in greater engine efficiency.

Natural gas has wider flammability limits than either gasoline or diesel fuel which, although undesirable from the safety perspective, results in leaner operating conditions and greater combustion stability. There are a number of conversion kits being marketed by Mogas, Ecofuels, Air Sensors/Impco (electronic fuel injection (EFI) conversion package) and ORTECH (gaseous fuel injection (GFI) conversion package). Both government and private researchers continue to examine ways of lowering the high cost of conversion, providing dedicated natural gas vehicles, and solving the problems of restricted driving range and limited fuelling facilities.

2.3.2 Distribution

Natural gas is delivered by gas utilities through pipeline distribution systems for commercial, industrial and residential uses. However, the lack of a vehicle refuelling network has restricted the use of natural gas to niche markets such as fleet operations--vehicles which have ready access to sufficient quantities of natural gas as well as load capacity constraints and vehicle travelling ranges which are well defined and not limiting factors.

Refuelling stations for natural gas vehicles are significantly different from those providing liquid fuels. The two options available for refuelling are known as the "fast-fill" and the "trickle-fill" which

differ, as their names suggest, in the speed at which they can fill a vehicle's cylinders. The fast-fill system allows a vehicle to be refuelled within three to five minutes (similar to traditional gasoline stations), whereas a trickle-fill system can take several hours.

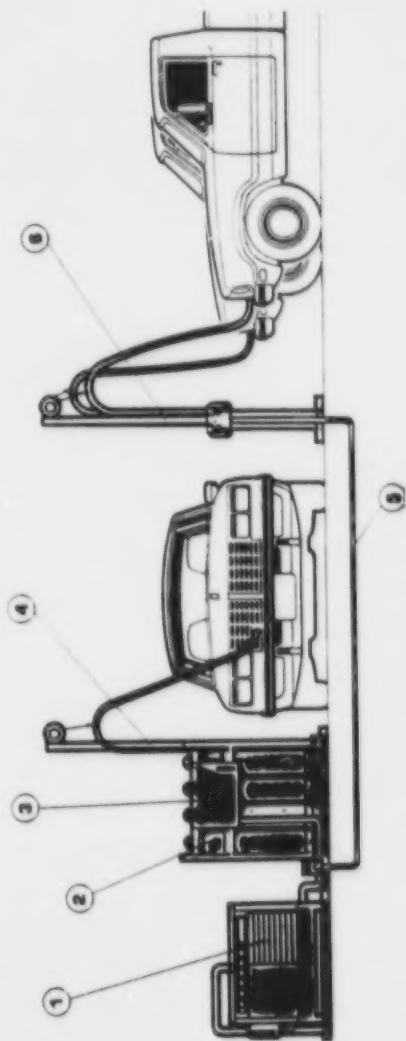
At a fast-fill refuelling station, natural gas is drawn from a low pressure gas main into a compressor which compresses the gas to about 3600 pounds per square inch (psi) and stores it in a cascade or bank of large cylinders. When the system is turned on, a regulator panel connected to the storage cascade allows vehicles to be filled up to a pressure of 3000 psi. A regulated supply of natural gas is allowed to pass from the storage cylinders via a fill post assembly, or dispenser, directly into the cylinders in the vehicle.

In a trickle-fill or "slow-fill" refuelling station, a fleet of vehicles may be filled directly from the compressor over several hours. In this system, the compressor pumps natural gas through high pressure piping to each fill post assembly. A refuelling station of this type designed for fleets of varying sizes may consist of a number of fill post assemblies, each one equipped to fill two or four vehicles at a time. Natural gas passes from the fill post assemblies to the cylinders in each of the vehicles (see Figure 2.4).

In 1990, there were 117 public service stations across Canada equipped to provide natural gas for vehicle use.² If natural gas is to provide a greater percentage of passenger car fuel requirements, this number will obviously have to be increased. However, the fast-fill stations which would be necessary, although more convenient than trickle-fill facilities, would also be more expensive due to the need for additional equipment and maintenance. Currently, fleet operators with the option of using the trickle-fill system for overnight refuelling could benefit financially from the savings due to the lower compression requirements which this procedure demands.

The design of the fuelling system contained within natural gas vehicles themselves also differs significantly from the refuelling system contained in liquid fuel burning vehicles. A small, high pressure fitting from the fill post is inserted into a receptacle on the vehicle. Once the valve controlling the high pressure gas flow from the compressor is opened, the line becomes pressurized and the flow of natural gas is controlled by a valve on the refuelling probe. Backflow is prevented by a check valve in the fuel line. The main high pressure control valve is shut off when the vehicle's tanks are full, thus preventing the continued flow of product from the compressor. Before

Figure 2.4
Natural Gas Refuelling Stations



SOURCE: *Natural Gas Vehicle Fuel, The Natural Alternative to Gasoline and Diesel*, Canadian Western
Natural Gas Co.

removing the refuelling probe, a bleed valve is opened which releases the pressure in the line between the shutoff valve and the check valve. The dust plug or high pressure fitting is then replaced in the vehicle receptacle.

Though the natural gas refuelling procedure may sound fairly complex, in actuality the process has been designed to be suitable for public use. An interesting and most convenient concept currently being studied and tested is the feasibility of installing compressors in or just outside private garages for overnight refuelling of vehicles (see Figure 2.5).

2.4 Vehicle Options

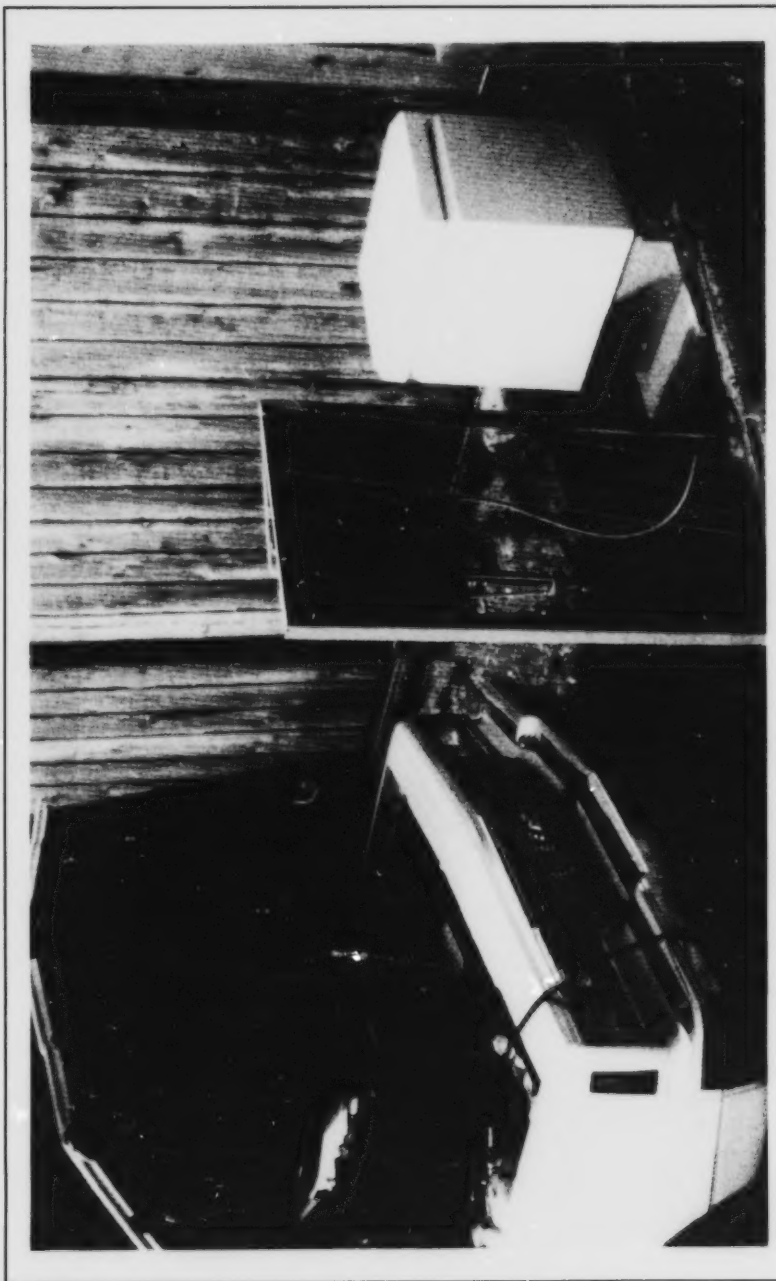
It is relatively simple to convert existing gasoline engines to operate on natural gas since natural gas engines, like their gasoline counterparts, are generally spark-ignited.

Most natural gas vehicles in operation today were originally designed to run on either gasoline or diesel fuels. No major vehicle manufacturer commercially produces a standardized natural gas fuelled vehicle. Retrofitted natural gas vehicles are dual-fuel, requiring engine modifications to allow them to operate on fuels with different physical characteristics. A number of manufacturers have conversion kits available for spark-ignition engines. While these conversion kits can generally be fitted to a variety of engine models, the gas mixing devices attached to the carburetor must be appropriately configured for each specific engine design.³ Conversion kits available for diesel engines, on the other hand, usually require substantial modification before they can be used on engine models other than the particular one for which they were originally designed.

2.4.1 Dual-Fuel Systems - In which Vehicles are Converted from Gasoline to Natural Gas and Operate on One Fuel at a Time

Most converted vehicles have their gasoline fuel systems left intact, because of the limited driving range attained and the lack of refuelling stations. Although natural gas has the disadvantage of having a very low energy density, it is an excellent fuel for internal combustion engines. The combined availability of both fuels actually increases a vehicle's driving range. But, the combined weight of the two fuel systems usually results in inferior performance and fuel economy than would be achieved by a vehicle designed or converted to operate entirely on either gasoline or NGV. In fact, retrofitted gasoline

Figure 2.5
Natural Gas Home Refuelling Appliance



SOURCE: Wyman, R.E., Canadian Hunter Exploration Ltd.

vehicles, with electronic fuel injection, suffer a 10 to 20 percent reduction in peak power when operating on NGV (see Figure 2.6).⁴

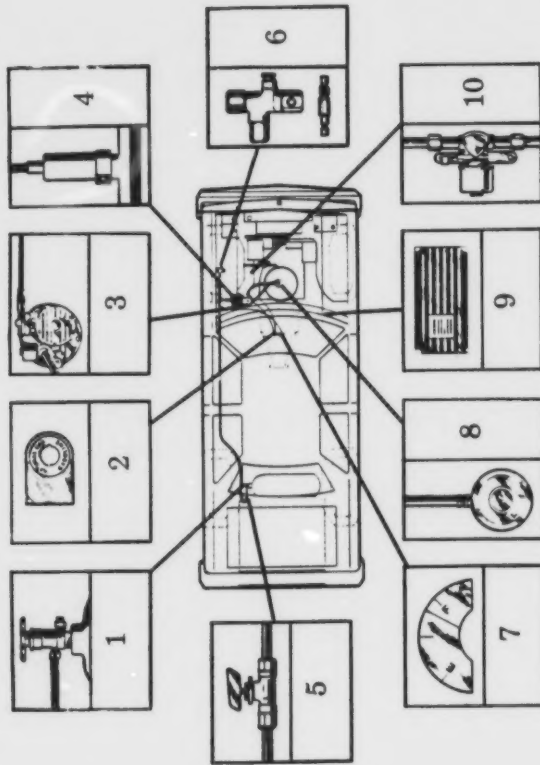
2.4.2 Dual-Fuel Systems - In which Vehicles are Converted from Diesel Fuel to Natural Gas and Operate on a Combination of Natural Gas and Diesel Fuel or Diesel Fuel Alone

The cetane number of a fuel reflects the ignition capability of the fuel in a compression-ignition engine. Natural gas has a low cetane value and is incapable of auto-ignition (requiring temperatures $> 650^{\circ}\text{C}$) in engines designed to operate on diesel oil as these engines typically specify a minimum cetane value of 40 (diesel oil is usually in the range of 45 to 55). By modifying diesel engines to operate at higher ignition temperatures and with the use of glow plugs, natural gas may be auto-ignited in the same way as other fuels which have a low cetane value such as methanol (5 cetane, auto-ignition temperature $> 470^{\circ}\text{C}$) or ethanol (15 cetane, auto-ignition temperature $> 392^{\circ}\text{C}$).

To obviate the necessity of redesigning the engine, a diesel pilot ignition technique may be used in which diesel fuel is used to ignite the gas/air mixture. The diesel fuel is introduced in the normal fashion at light loads but natural gas is added to the air charge to provide power at intermediate and high loads. The high efficiency of the diesel cycle is maintained and the cleaner burning fuel provides most of the power during the period when diesels emit the heaviest pollutants. The percentage of natural gas used would vary from zero at idle to 90 percent at full power with typical averages for highway driving in the region of 70 to 80 percent. Vehicles are usually configured to automatically revert to full diesel operation when the natural gas tank pressure drops to a predetermined low value.

Alternatively, a spark-ignited version of the "diesel" engine may be used. As most gaseous fuelled "diesel" engines have been designed for stationary use (pumping, power generation, etc.), considerable modification may be required to enable the engine to perform satisfactorily under the demands of automotive use. Typical efficiencies obtained from these engines are intermediate between those obtained for light duty "gasoline" automotive and traditional heavy duty, diesel oil fuelled engines.⁵

Figure 2.6
Vehicle Conversion



(Continued on Next Page)

Figure 2.6 (Continued)

- 1) **CYLINDERS** - Selected from a variety of sizes and types, they are matched to the vehicle's size. Each is equipped with individual shut-off valves.
- 2) **FUEL SELECTOR SWITCH** - Permits the driver to change from natural gas to gasoline and back without stopping.
- 3) **REGULATOR** - Accepts natural gas from storage cylinders, and feeds this gas to the mixer in response to demand and vacuum signals from the intake system. It also features a built-in gas solenoid valve with vacuum lockout, engine idling device, gas primer, water circulation ports and a replaceable gas filter element.
- 4) **FUEL GAUGE TRANSDUCER** - Signals the pressure in the vehicle cylinders.
- 5) **MASTER SHUT-OFF VALVE** - Is normally left open, but allows all the natural gas to be shut off at the cylinder.
- 6) **FILLING CONNECTION** - This fitting includes a non-return valve that automatically seals the system after refueling. A dust plug prevents dirt from entering the filling connection.
- 7) **FUEL GAUGE** - Indicates the amount of natural gas left in the cylinders. It may be mounted near the selector switch or on the dashboard.
- 8) **MIXER** - Is connected to the regulator by low pressure tubing. It is specifically designed for efficient mixing and correct flow rate for the carburetor and the engine.
- 9) **DUAL CURVE IGNITION BOX** - Advances ignition timing for natural gas.
- 10) **GASOLINE SOLENOID VALVE** - Electrically operated, shuts off gasoline to the carburetor when natural gas is being used.

SOURCE: *Natural Gas, An Alternative Transportation Fuel*, Energy, Mines and Resources, Canada.

2.4.3 Mono-Fuel Systems

Recognizing the driving force behind the introduction of alternative fuels as being the environmental issue, vehicle manufacturers, particularly of light-duty vehicles, are becoming interested in producing a mono-fuel system. Such systems would have the potential to cut emissions levels to a greater degree than is possible with dual-fuel vehicle options.

Mono-fuel natural gas vehicles, designed by the OEMs to operate solely on natural gas, are still in the developmental stage. Optimized combustion chamber designs and fuel metering systems which would provide the necessary performance, fuel economy, and emissions control are still being developed. When these vehicles become commercially viable, they will:

- have the storage tanks designed into the vehicle in a manner which provides greater on board fuel holding capacity, thereby increasing the driving range;
- have emissions below those of gasoline (with the exception of nitrogen oxides, which will likely remain about the same or slightly higher); and
- be marketed at a cost slightly less than retrofitted vehicles (perhaps \$1000 versus \$2000 to \$3000).

Unfortunately, modifying or designing and marketing a vehicle to operate solely on natural gas would require increasing the compression ratio from eight to twelve, so that the vehicle could no longer operate on gasoline. Although increasing the compression ratio can reduce fuel consumption and raise the power output, at present a mono-fuel natural gas vehicle option is not practicable because the necessary fuelling infrastructure is not in place.

2.5 Environmental Impacts

2.5.1 Natural Gas Production and Processing

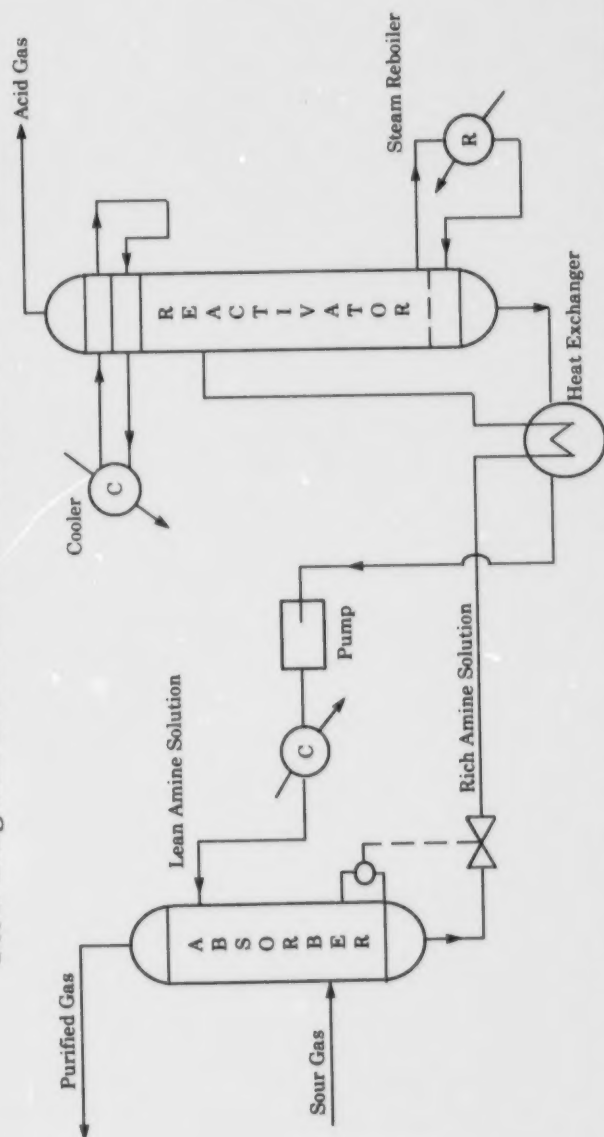
Accompanying the increased use of alternative fuels will be the requirement of additional throughput at the production stage. It is essential when determining the environmental significance of these fuel sources that the increased emissions emanating from the incremental production and processing of the fuel be taken into consideration. However, it must also be recognized that diverse feedstocks

and process technologies can and do result in differing concentrations of emissions (see Table A.4).

As noted earlier, wellhead gas requires the removal of a number of impurities before it can be shipped via pipeline. The level and type of impurities in the gas are dependent upon how sweet or sour it is. Sour gas contains levels of H_2S that are unacceptable for combustion. Alberta, from which flows most of Canada's gas production, produces grades of gas that contain as little as one part per million (ppm) to as much as 60 percent sulphur content.⁶ As the sulphur content from the well cannot be greater than 4 percent if it is to be transported by pipelines, much of the gas being produced must be processed before being shipped. Once the natural gas has been passed through a field separator to remove the water and hydrocarbon condensate, the remaining liquefiable constituents such as propane, butane and natural gasoline are recovered in a gas processing plant. A gas sweetening plant then removes the sulphur to convert the sour gas to sweet (see Figure 2.7).

Hydrogen sulphide from the sweetening plants is the major pollutant associated with the natural gas processing industry. The hydrogen sulphide removed from sour natural gas can be disposed of via a number of processes: it can be flared (either through a waste gas flare or a modern smokeless flare), vented, incinerated, or used for the production of elemental sulphur. The latter disposal procedure results in almost complete process recovery, with only 0.1 percent of the sulphur being released into the atmosphere. Table 2.2 provides estimates of the emissions from the sweetening process as well as from the field gathering and process plant engines of sour natural gas with a 20 percent sulphur concentration. Other smaller emission sources are the compressor engines, both those used to transport the gas to the processing plant and those used in the processing plant. Both carbon dioxide and nitrogen oxide emissions from those compressor engines are a concern (see Figure 2.2).⁷

Figure 2.7
Flow Diagram of the Amine Process for Gas Sweetening



SOURCE: *Cost-Effectiveness of Alternative Transportation Fuels in Urban Bus Operations*, CANMET.

TABLE 2.2
EMISSION FROM NATURAL GAS PROCESSING
(grams emissions/m³ gas processed)

Process	Part.	SO _x ^b	CO	HC	NO _x	CO ₂ ^a
Amine Process	Neg.	0.1665	Neg.	Neg.	Neg.	N/A
Field Collection	N/A	0.0005	0.097	0.0144	0.235	N/A
TOTAL	N/A	0.1670	0.097	0.0144	0.235	104.1

SOURCE: Canada Centre for Mineral and Energy Technology, *Cost-Effectiveness of Alternative Transportation Fuels in Urban Bus Operations*, prepared by SYPHER:MUELLER International Inc. for the Efficiency and Alternative Energy Technology Branch, Energy, Mines and Resources Canada (Ottawa, Ontario, November 1989).

2.5.2 Vehicular Emissions

Little data is available in Canada on either the evaporative or exhaust emissions from retrofitted natural gas vehicles. However, as with all fuels, exhaust emissions are determined not only by engine and vehicle design but also by driving patterns. Methane is a simpler hydrocarbon than those found in gasoline and will mix more uniformly with air. As a result, in properly adjusted engines, more complete combustion should occur producing lower levels of unburned hydrocarbons. Also, as a natural gas engine does not have to be warmed up or choked, cold start emissions--which constitute a large part of the city cycle emissions--should be considerably reduced.⁸

Nitrogen oxide is a product of high temperature combustion in the presence of excess oxygen. Although peak combustion temperature in spark-ignition engines is generally lower for natural gas than gasoline, if the natural gas is set to contain greater amounts of excess oxygen than the gasoline has, the result will be increased NO_x emissions. Also, in high compression spark-ignition engines which are set to optimize the potential of the high octane number of natural gas, NO_x emission levels may be higher than for gasoline due to higher combustion temperatures.

In dual-fuel diesel engines, a high natural gas substitution ratio combined with high load conditions could result in higher NO_x emission levels than are produced when operating solely on diesel fuel. Conversely, lower load conditions may result in dual-fuel diesel

engines producing NO_x emissions equivalent to those produced from conventional diesel operations.⁹

Carbon monoxide levels from spark-ignition engines operating on lean burning natural gas should be small relative to gasoline (see Figure 2.8). In diesel engines, however, CO emissions, although relatively small whether from spark-ignition engines using natural gas or dual-fuel engines operating on a combination of natural gas and diesel fuel, will still likely be greater than when operating on only diesel fuel.

With proper fuel metering, diesel engines converted to dual-fuel will provide a reduction in particulate emissions when compared to conventional diesel operations. However, should the fuel control system for natural gas and diesel fuel be improperly adjusted, over fuelling can result in smoke.¹⁰

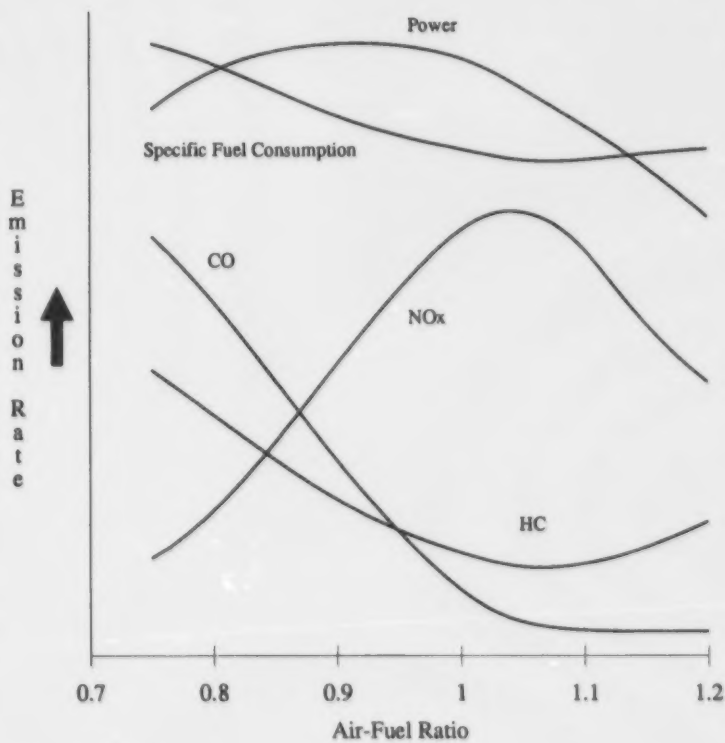
It is important to recognize when buying a conversion kit, that unless it is properly installed by a mechanic certified to convert gasoline vehicles into dual-fuel vehicles, increased emissions may result when operating the vehicle on gasoline. Emissions when operating on natural gas may be the same or only insignificantly lower. Also, dedicated natural gas vehicles would likely achieve much better emission standards than those which are suggested to be attainable by dual-fuel vehicles.

Following is a summary of the emissions results from a recent study issued by the United States Environmental Protection Agency (EPA), which considered the use of natural gas in passenger cars, light trucks and heavy-duty vehicles.

2.5.2.1 Light-Duty Dual-Fuel Vehicles

Table A.5 projects natural gas dual-fuel vehicles emitting up to 47 percent less non-methane reactive hydrocarbons (NMHCs) than proposed future gasoline vehicles. Carbon monoxide emission reductions are also achievable, although the EPA testing indicated that reduced CO emissions with natural gas are not a natural property of the fuel. In fact, the vehicles under consideration required recalibrating in order to lower their CO emissions. These recalibrations resulted in slightly higher NO_x emission levels. It appears that calibrating a car slightly rich of stoichiometric to achieve low NO_x emissions tends to increase the production of CO.

Figure 2.8
Emissions as a Function of
Air-Fuel Ratio



SOURCE: Owen, K., Coley, T., Automotive
Fuel Handbook, 1990.

Another trend that can be observed from Table 2.3 is that NO_x emissions can increase when using natural gas rather than gasoline. As indicated, the Delta 88, the Celebrity and the GMC Pickup all suffered NO_x emission increases while the Crown Victoria and the Ford LTD experienced slight improvements in NO_x emissions. The higher NO_x emissions can be the result of burning natural gas at lean air-to-fuel ratios as well as using advanced spark timing to improve performance by compensating for the lower flame speed of methane.

2.5.2.2 Light-Duty Dedicated Vehicles

Table A.5 suggests future optimized dedicated natural gas vehicles will be capable of an 80 to 93 percent reduction in NMHCs, as compared to future gasoline vehicles. These reductions are attributed to the elimination of evaporative emissions, running loss emissions and refuelling losses in these dedicated vehicles.

As noted earlier, future dedicated natural gas vehicles will likely result in CO reductions. However, this will require a high compression, lean-burn engine optimized to provide CO benefits while maintaining NO_x emissions within acceptable levels.

2.5.2.3 Heavy-Duty Dual-Fuel Vehicles

Again, very little heavy-duty dual-fuel emissions data is available, although past testing on light-duty vehicles indicates the addition of a dual-fuel natural gas conversion kit to a heavy-duty gasoline vehicle can actually degrade the emissions performance of the vehicle when operated on gasoline. As noted earlier, a dual-fuel engine designed to fully optimize the potential of natural gas will compromise the engine's ability to operate at its optimum potential on gasoline.

Emissions data for lean-burn dual-fuel NGV engines with diesel fuel pilot ignition are also somewhat sparse, with very little testing having taken place and with the results of the testing to date providing rather mixed findings. That there is a need for a great deal more research and development is inherent in the knowledge that the properties of natural gas vary significantly from those of gasoline or diesel fuel. Yet, dual-fuel vehicles are capable of providing the operator with flexibility in fuel choice while the necessary refuelling infrastructure for NGV is being put into place.

TABLE 2.3

EXHAUST EMISSIONS FROM CNG/GASOLINE DUAL-FUEL CARS
(grams per mile over the EPA Federal Test Procedure)

Site	Test Vehicle	Fuel	NMHC ^a	CO	NO _x	Eff.1 ^b	Eff.2 ^c	Accel ^c
EPA	CNG Fuel System 1984 Delta 88	Gasoline CNG	0.30 0.25	9.8 1.7	0.40 1.18	-15% -7%	Base +10%	Base -30%
EPA	Total Fuels 1987 Crown Vic.	Gasoline CNG	0.27 0.36	1.4 0.5	1.07 0.93	-15% -13%	Base +4%	Base -27%
EPA	Wisconsin Gas 1987 Celebrity	Gasoline CNG	0.20 0.16	1.3 0.1	0.60 1.19	-15% -8%	Base +8%	Base -31%
CARB	Dual Fuel System 1983 Ford LTD	Gasoline CNG	0.36 0.35	3.3 0.1	0.56 0.47	NA NA	Base -20%	NA NA
CARB	Pacific Light 1985 GMC Pickup	Gasoline CNG	0.26 0.05	7.0 0.2	0.70 1.06	NA NA	Base -20%	NA NA

SOURCE: Environmental Protection Agency, *Analysis of the Economic and Environmental Effects of Compressed Natural Gas as a Vehicle Fuel, Volume 1, Passenger Cars and Light Trucks* (Ann Arbor, Michigan: Office of Mobile Sources, April 1990), p. 29.

^aNon-methane HC was calculated assuming that methane was equal to 25 percent of gasoline HC emissions and 90 percent of CNG HC emissions for EPA test vehicles.

^bPost-conversion energy efficiency over the FTP relative to EPA certification fuel economy data for the specific gasoline vehicle model.

^cThese final two columns use the post-conversion gasoline fuel mode as a baseline for comparison with the CNG fuel mode (negative numbers mean lower efficiency or less acceleration with CNG).

2.5.2.4 Heavy-Duty Dedicated Vehicles - Lean-Burn Combustion

Table 2.4 provides a summary of the emissions design targets of Cummins Engine Company, which is currently developing a natural gas version of its L-10 heavy-duty diesel engine for commercial introduction to the bus engine market in 1991. The two configurations which Cummins has been evaluating involve:

- (1) a mechanical diaphragm mixer manufactured by IMPCO Carburetion, Inc. with separate idle and full power adjustments. This open loop system does not utilize an exhaust sensor for automatic air-fuel ratio control; and
- (2) an open loop, electronically controlled venturi type mixer manufactured by TNO Road Vehicles Research Institute in Holland.¹¹

TABLE 2.4
SUMMARY OF LOW MILEAGE EMISSIONS FROM
LEAN-BURN CNG ENGINES OPERATED OVER THE
EPA HDDE TRANSIENT TEST CYCLE
(grams per BHP - hour)

Pollutant	Cummins CNG L-10 Design Targets	Cat. 3406 w/o catalyst	1991 Diesel Standards	Assumed Current CNG Technology
THC	0.9	9.2	1.3	0.9
NMHC	---	0.84	---	0.09
NO _x	4.5	4.1	5.0	4.5
Particulates	0.06	0.6	0.25/0.10 ^a	0.06
CO	4.0	3.2	15.5	4.0
CO ₂	---	---	---	575
Formaldehyde	---	0.34	---	0.05

SOURCE: Environmental Protection Agency, *Analysis of the Economic and Environmental Effects of Compressed Natural Gas as a Vehicle Fuel, Volume II, Heavy-Duty Vehicles*, Special Report (Ann Arbor, Michigan: Office of Mobile Sources, April 1990), p. 3-17.

^aThe 0.10 standard applies to urban bus engines only. The 0.25 standard applies to all other heavy-duty diesel engines.

It should be noted in Table 2.4, which also includes emissions tests from a Caterpillar 3406, that although current technology is assumed to be capable of providing levels of particulates as low as 0.06 grams per brake-horsepower hour, the combustion in the Caterpillar engine resulted in particulate levels ten times as high. As the

particulates were determined to be 90 percent soluble organics, it is believed this higher particulate level was due to lubricating oil passing the piston ring pack and entering the combustion chamber. Considerable efforts to improve oil control and reduce engine-out particulate levels have resulted in low oil consumption designs being successfully incorporated into diesel engines, assuring the EPA there should be no problem for the 1991 heavy-duty, lean-burn, dedicated natural gas engines to meet the particulate standards.¹²

2.5.2.5 Heavy-Duty Dedicated Vehicles - Stoichiometric Combustion

Table 2.5 summarizes the emissions data from a converted Chevrolet 454 gasoline engine that was converted to a dedicated stoichiometric heavy-duty natural gas engine for use by Brooklyn Union Gas (BUG). In comparing these results with those in Table 2.4, it can be observed that the HC emissions are similar for both the lean-burn and stoichiometric engines while the NO_x , formaldehyde and particulate levels from the lean-burn tests are higher than from the stoichiometric. Although the carbon dioxide levels of the stoichiometric engine were also lower than for the lean-burn engine, the carbon monoxide levels were higher.

In order to summarize the emissions reduction potential of natural gas as a transportation fuel, it is necessary to reiterate that this fuel is primarily methane and that methane has a low reactivity in terms of atmospheric ozone formation. On average, each vehicle in the current fleet of approximately 25,000 natural gas vehicles operating in Canada is credited with reducing non-methane, volatile organic compounds (VOCs) by approximately 32 kilograms annually.¹³ Should the natural gas vehicle population grow to 50,000 vehicles by 1995, therefore, the annual VOC emissions would conservatively be reduced by over 1600 tonnes per year. "Conservatively" is stressed in this instance as further technological developments in conversion kits or OEM factory produced vehicle models will likely raise the emission reduction capabilities even more.

As the natural gas conversion kits available to date were designed to provide the user with lower fuel costs and energy diversity, without the requirement for reducing emissions, the inherent characteristic for natural gas to burn hotter in the cylinders than gasoline results in higher NO_x levels. The conversion kits being designed today, with their consideration of environmental concerns, computer fuel control systems and lean-burn technology, should provide the

TABLE 2.5
SUMMARY OF LOW MILEAGE EMISSIONS FROM
THE BROOKLYN UNION GAS (BUG)
STOICHIOMETRIC CNG ENGINE
(g/BHR-hr)

Pollutant	IMPCO Mixer		TNO Mixer		Applicable Standards
	w/o Catalyst	w/ Catalyst	w/o Catalyst	w/ Catalyst	
Diesel Test Cycle					
THC	3.6	1.03	3.57	1.01	1.3
NMHC	0.82	0.15	0.83	0.17	---
NO _x	6.62	1.33	6.87	1.16	5.0
Part.	0.01	0.01	0.01	0.01	0.25/0.10 ^a
CO	31.9	10.8	23.3	6.64	15.5
CO ₂	529.0	557.0	520.0	540.0	---
Formaldehyde	0.03	0.0008	0.02	0.0007	---
Gasoline Test Cycle ^b					
THC	1.7	0.72	1.47	0.84	1.1/1.9 ^c
NMHC	0.40	0.09	0.34	0.12	---
NO _x	5.75	0.51	6.57	1.46	5.0
Part.	0.01	0.01	0.05	0.01	---
CO	28.5	10.6	8.16	4.54	14.4/37.1 ^c
CO ₂	474.0	500.0	471.0	504.0	---
Formaldehyde	0.02	0.0001	0.02	0.0007	---

SOURCE: Environmental Protection Agency, *Analysis of the Economic and Environmental Effects of Compressed Natural Gas as a Vehicle Fuel, Volume II, Heavy-Duty Vehicles* (Ann Arbor, Michigan: Office of Mobile Sources, April 1990), p. 3-19.

^aThe 0.10 standard applies to urban bus engines only. The 0.25 standard applies to all other heavy-duty diesel engines.

^bThe without catalyst results are hot start results only, not composite.

^cThe less stringent standards apply to engines used in trucks greater than 14,000 lb. GVWR.

capability of reducing NO_x levels to approximately those of a gasoline engine. On the other hand, natural gas can provide a substantial reduction in NO_x emissions, when compared to diesel, as can be noted from Table 2.5.

Although natural gas engines may not currently be optimized to operate as efficiently as gasoline engines, there should still be some reduction in CO_2 emissions when operating a vehicle on natural gas as it contains less carbon per unit of energy than gasoline (see Table A.6). Unless methods to reduce the levels of unburnt natural gas released through the exhaust can be developed, however, any gains made towards reducing the greenhouse effect through lower CO_2 emissions may be lost (see Table A.7).

Also as noted above, the sulphur content of the natural gas can be almost eliminated by removing and storing it as elemental sulphur. This provides a potential for a reduction in sulphur oxide (SO_x) emissions when compared to using diesel fuel.

Natural gas has the potential to reduce the amounts of carbon monoxide, carbon dioxide and particulates being emitted into the atmosphere, particularly in urban environments. However, more research and development will be necessary in order to optimize on the potential environmental benefits of natural gas engines without increasing NO_x levels.

2.6 Health and Safety Hazards

Experience has shown natural gas to be a relatively safe fuel. Though there are over 500,000 natural gas vehicles on the road throughout the world, there have been no reported deaths directly attributable to the use of natural gas. According to an American Gas Association safety survey published in 1987, injury rates per mile for natural gas vehicles in the United States were 84 percent lower than for all other registered vehicles.¹⁴

The physical characteristics of natural gas offer a number of built-in safety advantages in the case of collisions and/or accidental release. Since NGV is less dense than air, it disperses immediately upon release, eliminating the possibility of pooling and reducing the risk of an explosion. Additionally, natural gas possesses a higher auto-ignition temperature than either gasoline or diesel fuel, which suggests that a natural gas leak is less likely to result in a fire (see Table A.1).¹⁵

Natural gas is non-toxic. It becomes dangerous only if sufficient quantities are present in a closed space to actually displace the air and cause suffocation. To ensure safety, odourants are added to the fuel to assist in its detection, should leaking occur.

The primary safety concern when using natural gas in vehicles arises from the rapid release of gas from the high pressure storage tanks. As NGV is stored under high pressures, it has greater potential than gasoline for escaping from the fuel system. This concern has resulted in stringent regulations and standards which guarantee that the fuel storage cylinders are stronger and more damage resistant than available gasoline tanks. Experiments involving crashes, explosions, drop tests from high altitudes, and even shooting bullets directly at NGV tanks have concluded that the licensed natural gas cylinders being installed in NGV vehicles are probably the safest part of these vehicles.

As a fire safety measure, NGV storage tanks have been equipped with pressure relief valves to vent the gas under controlled conditions in the case of a vehicle fire. "Melting plugs" which vent gas from a storage tank at a preset temperature are one example of the types of pressure relief mechanisms incorporated into cylinder designs.

Regulations governing NGV vehicle conversions and refuelling stations are the responsibility of the provincial governments. However, the Canadian General Standards Board (CGSB) does outline national standards as developed by the Canadian Gas Association. These standards are presented in Appendix B.

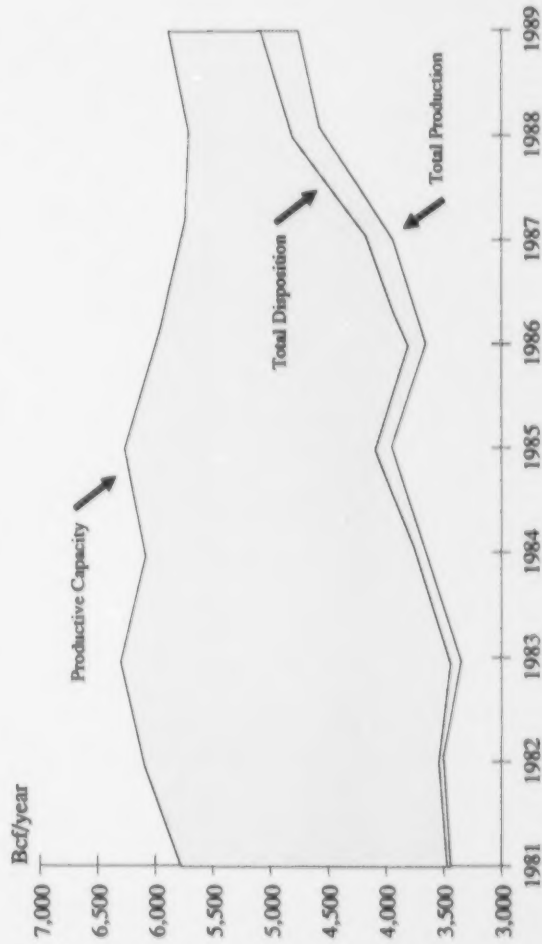
2.7 Economic Assessment

2.7.1 Demand

The recession of the early 1980s resulted in a temporary decline in the growth of natural gas consumption. More recently, the former upward trend in natural gas sales has been re-established, albeit at a lower growth rate than was previously experienced (see Figure 2.9).

The current surplus of natural gas production capacity has prompted both industry and governments to search for new and expanded domestic and export markets. Canadian gas producers look towards the eastern provinces as well as the United States for increased market potential. Significant new markets for natural gas may also include industrial cogeneration and select gas use, fuel cells

Figure 2.9
Canadian Natural Gas
Domestic Production and Demand



SOURCE: National Energy Board.

and heat pumps, in addition to the transportation industry. Any upsurge in Canadian gas usage, however, will be dependent upon government energy policies (especially with regard to environmental issues), technology, and ultimately the expected price of this energy source in relation to the cost and availability of competing fuels.

Although natural gas has been recognized as a motor vehicle fuel for decades in countries such as Italy and New Zealand, it is only since the early 1980s that the transportation market has been seen to represent a significant sales opportunity for natural gas producers in the United States and Canada.¹⁶ Despite the increasing interest in this new market, it should be noted that the total volume of natural gas likely to be used in vehicles in the near future is only a small fraction of that presently utilized in other sectors of the economy. If 5 percent of the vehicles in Canada were converted to natural gas (which would represent a more than thirty-fold increase over the current natural gas fleet), the demand for natural gas would rise by approximately 50 billion cubic feet annually.

If the market for natural gas as a vehicular fuel is to expand to its full potential, efforts will have to be made to identify consumers who stand to gain from conversion to natural gas, and ensure that these consumers are aware of the potential economic advantages of this fuel relative to other alternatives. Due to the lack or perceived lack of refuelling stations, as well as the high conversion cost which must be recovered before net economic gains can be realized by the consumer, the principal target markets for NGV conversion will be high mileage fleet vehicles, typified by taxi-cabs, delivery vehicles, school and commuter buses, and other municipal fleets. Innovations in NGV/diesel engine designs for heavy-duty trucks in answer to environmental concerns could also contribute towards the expansion of demand for natural gas for use in vehicles.

2.7.2 Reliability of Supply

The western provinces account for most of Canada's natural gas output, with Alberta and British Columbia supplying 97 percent of the quantity produced from conventional areas. Commercial scale reserve additions have also been established in Canada's northern frontier and east coast offshore regions, although at today's prices these sources remain uneconomic. Continued growth in gas production will require increased penetration into the United States export markets, a sustained rise in oil prices, and/or sustained concern and actions regarding environmental emissions. Overall, production

capacity remains far above current demand for both the domestic and export markets, although recent contracts with the United States have provided new outlets for a portion of Canada's production potential.

According to the 1988 National Energy Board (NEB) supply/demand analysis, Canada has a natural gas reserves-to-production ratio of 22,^{17,18} a ratio which is likely to increase if investment trends in favour of gas exploration continue. This suggests that the production of sufficient quantities of natural gas to satisfy current and projected demands at prices competitive with other energy sources should not pose a problem for Canada. In addition to its large raw natural gas resources, Canada also possesses substantial reserves of coal and biomass, the two other feedstocks which can be used in the production of natural gas for fuel.

With regard to distribution, with the recent agreement to extend the WestCoast pipeline system to Vancouver Island, natural gas will be readily available in all of the urban centres west of the Atlantic provinces. As pipelines already exist to supply traditional consumers of natural gas in urban areas, and given that the potential demand for natural gas for use in vehicles is fairly modest when compared to the total natural gas market, the marginal cost of transporting increased quantities of natural gas for vehicles in heavily populated regions should be fairly low. This could be especially true if the increased demand resulted from the widespread use of home compressors for overnight refuelling of personal vehicles, which would boost natural gas use during off-peak periods. In sparsely populated corridors in northern regions, as well as between major urban centres, where both new fuelling facilities and pipeline facilities would be necessary, this marginal cost would be higher.

2.7.3 Incentives

Due to Canada's large gas reserves base, as well as the fact that current production far exceeds domestic demand, major commitments from industry and governments have been undertaken in an attempt to encourage increased usage of compressed natural gas in the nation's vehicles.

2.7.3.1 Federal Incentives

A primary objective of the 1980 Canadian National Energy Program was to achieve oil self-sufficiency and eliminate oil imports by 1990. Recognizing the potential for substituting domestic natural gas

for a portion of the oil being utilized in the transportation industry, and prompted by favourable experiences with this fuel in countries such as Italy, Australia and New Zealand, major commitments were made throughout the 1980s to the research and use of compressed natural gas vehicles. Prior to 1990, Energy, Mines and Resources Canada (EMR) had already invested over \$6 million in grants through the prevailing natural gas programs to promote further use of the fuel in the transportation sector. Funds from the remaining Market Development Incentive Program (MDIP) will be provided to ensure the continuation of a number of the ongoing federal initiatives as well as to provide for a few new incentives. The MDIP fund was set up by the Federal Government based on financial contributions from Alberta producers seeking new natural gas markets.

As a prime moving force behind the promotion of research and the establishment of national standards for NGV, EMR has provided and continues to provide economic incentives for vehicle conversions:

- (1) The Natural Gas For Vehicles Program (NGVP), which provides \$500 for each vehicle conversion, is available in the Province of British Columbia until March 31, 1991 and Alberta and eastward until March 31, 1994, or to a maximum of 35,000 conversions. There are currently 25,000 converted vehicles, of which less than one-fifth are owned and operated by gas companies. (Of the 11,400 vehicles converted by the end of 1986, 45 percent were automobiles, 23 percent light trucks and 21 percent vans. Two-thirds were in fleets and the remainder in private use.)¹⁹
- (2) The Natural Gas Fuelling Station Program (NGFSP) provides \$50,000 for each new public NGV station until March 31, 1994 or until thirty new stations have been built. There are currently 117 natural gas fuelling stations in Canada.
- (3) The Residential Refuelling Appliance (RRA) Program is scheduled to begin on April 1, 1991 and continue to March 31, 1994, or to a maximum of 4,000 RRA conversion packages. \$1500 will be provided for each RRA vehicle conversion package, \$1000 of which goes towards the installation of an RRA and \$500 of which is actually a grant provided under the NGVP.
- (4) The Commercial Compression Program is designed to assist the natural gas utilities in attracting large fleets to NGV by helping to offset the costs of installing on-site NGV refuelling facilities. It provides contributions

of 25 percent of the capital costs of commercial NGV compressors, to a maximum of \$50,000 per compressor.

- (5) The NGV Market Development/Demonstration Program will provide up to 50 percent of the costs of specific development and demonstration projects designed to create new NGV markets. An initial project to receive funding under this program is the market demonstration of new RRAs and large commercial compressors in various locations throughout Alberta. As there is virtually no public refuelling network in Alberta that would be adversely impacted by the introduction of new compression facilities into the market, the province was judged to be an ideal location for such a demonstration, which could include up to 2,000 vehicles. Another possible candidate for funding under this program would be the development of NGV corridors, i.e., installing natural gas refuelling facilities along highly travelled routes such as the highways linking Windsor and Quebec City, Calgary and Edmonton, or Toronto and St. Catharines.
- (6) The NGV Technical Program, which consists of a research and development element combined with field trials and technical demonstrations, takes technology from the laboratory to the real world, identifies its commercial faults and initiates solutions. This program is designed to provide information for determining standards and regulations to assure the safety of systems and components. Major field trials currently underway in Ontario and to be followed in the near future in B.C. are testing the use of natural gas for fuelling urban transit buses.
- (7) The NGV Marketing Program is designed to complement activities under the other NGV programs and lend assistance to advertising and promotional requirements.

The total federal funding available specifically for NGV energy programs in Canada currently amounts to \$25,320,000. There are, however, other more generic federal incentive programs which affect natural gas as well, in addition to a variety of provincial incentive programs in such forms as road tax rebates, grants and utility incentives.

Natural gas is also exempt from the federal excise tax of 8.5 cents per litre on gasoline and 4 cents per litre on diesel fuel. Exemptions of this sort provide NGV with an added advantage in its marketplace competition with other vehicle fuels.

2.7.3.2 Provincial Incentives

Supplementing the Federal grants available for natural gas vehicle conversions, British Columbia provides an additional \$200 per vehicle converted in that province. Manitoba is the only province in Canada currently imposing a road tax on NGV. Both Ontario and British Columbia exempt natural gas from provincial road taxes which amount to 9.83 and 14.4 cents per litre on gasoline, respectively. Ontario also refunds the Ontario Sales Tax to a maximum of \$1000 if a vehicle is converted to NGV within six months of purchase. Neither Alberta nor Saskatchewan impose NGV road taxes. Quebec imposes a fuel tax of 8 percent which is applicable to all gas marketed for non-production purposes, including carburetion. According to Table D.1, which indicates the price of a litre of natural gas equivalent to a litre of gasoline in Quebec, this 8 percent tax amounts to 3.6 cents per litre of gasoline equivalent.

As with the exemption from the federal sales tax, it must be recognized that the short-term objective inherent in the road tax exemptions for natural gas is to make it a more viable product in the fuel market. In the longer term, however, it is unlikely that these tax holidays will be maintained beyond the point where the government begins to forego significant tax revenues. In other words, if natural gas is successful in gaining market share in the transportation fuel industry, it is reasonable to expect that these tax holidays would be reduced or eliminated. It is therefore important, when analysing the long-term economic viability of natural gas, to recognize that a major portion of the 40 to 50 percent savings when compared to the price of gasoline comes from these tax exemptions.

2.7.3.3 Natural Gas Price Incentives

Prior to the gradual decontrol of natural gas prices beginning in 1985, natural gas prices were established by the Federal and Provincial Governments at 85 percent of that of crude oil between 1975 and 1981, and then at 65 percent from 1981 to 1985. Plunging oil prices in 1986 decreased dramatically the differential between crude oil and natural gas, detracting from the previous price incentive. However, the price gap has widened again recently with the rise in gasoline prices.

2.7.3.4 Utility Incentives

In addition to the generous government incentives to encourage vehicle conversions and fuel station construction, a number of gas utility companies in the country offer grants and other financial incentives such as cylinder rental, conversion grants and loans. Gaz Metropolitain Inc. of Quebec offers a \$900 conversion rebate, while B.C. Gas offers 9 percent financing for 36 months on conversions. A number of utilities in both Ontario and British Columbia have negotiated rate basing of new refuelling stations with the natural gas regulatory boards. Under this pricing policy, the cost of new natural gas stations is spread over all gas users under the assumption that increased usage of natural gas in the transportation industry is beneficial to all gas consumers.

Despite the incentives available, market acceptance of NGV has been relatively slow. The major barriers to public acceptance of this fuel appear to relate to storage of the fuel in high pressure storage tanks, the availability of refuelling stations, the cost of conversion, and driving range limitations. Those who favour converting to natural gas do so because of the lower fuel price, expectation of lower emissions, assurance of ample domestic supply, and longer engine life.

2.7.4 The Empirical Assessment of the Value of Natural Gas

In evaluating the financial viability of alternative fuels, one must consider the limitations attached to the word "alternative". Alternative fuels have not had the investment funds spent on developing the infrastructure that is currently in place for gasoline and diesel fuel. This means that the initial market penetration of any of the alternatives being considered will require the expenditure of additional research and development funds in order to ensure that the industry expands to its potential. Some of these up-front financial obligations will ultimately be incorporated into the costs paid by the consumer.

The point to be made is that although the following analysis attributes fairly substantial costs to the conversion of gasoline and diesel engines to natural gas, involvement by the OEMs could reduce the cost differential to as low as the incremental cost between the natural gas cylinders being utilized and the gasoline tank which they replace. The same applies to equipment such as home compressors. If a new community was being developed and home compressors were

installed while the gas lines and wiring were being placed, or if it was built in a manner which would allow sharing of the costs across more than one homeowner, the high costs of retrofitting with piping and 220 wiring could be lowered substantially.

Maintenance expenditures are another factor which ultimately reflect higher costs in the initial stages of market development than later in the process of the industry's maturation, when personnel become more familiar with the technology involved. In particular, with natural gas engines, oil changes and spark-plug replacements may not necessarily be as frequent, but the added weight of the cylinders may result in the need for more frequent installation of new brakes over the vehicle's life. In actual fact, if these alternatives were designed and installed by the OEMs, it is likely that the maintenance costs applicable to these alternative vehicles would be comparable to the costs of gasoline or diesel engines, as the vehicle standards developed would be the same or similar. For this reason, maintenance costs are not included in the following analysis.

The cost of refuelling facilities for retail distribution is another financial variable which requires more complete information than is currently available. For the purposes of this analysis, only the incremental costs associated with the installation of the required compressor facilities were deemed to be relevant. When considering the costs of fleet refuelling facilities, this assumption led to an estimate of fleet compressor costs in the range of \$150-200 thousand. A residential refuelling facility or home compressor (net of incentives) was considered purchased at \$1500. As with the costs associated with fuel production and incremental vehicle conversion, the costs of the home compressors and/or the start-up capital necessary to build new or to modify an existing retail station for natural gas are likely to be passed onto the consumer.

There is one more "cost", the environmental cost, that ultimately influences the individual decision maker as well as the legislative directives being determined by policy makers in both industry and government. Whether or not a financial value can be attached to lower emissions is a very important social and political issue. If such a financial value could be accurately assigned to the marginal environmental cost of the emission of HCs, CO, CO₂, NO_x, and SO₂, and if these costs were used to apply taxes to all fuels on the basis of their specific emission profiles, then the economic

value of alternative fuels to the consumer could be greatly enhanced.

From the consumer's point of view, of course, the most influential consideration affecting decisions of whether or not to convert to an alternative fuel is the potential for cost savings. In the case of natural gas, the overall economics of conversion can be evaluated using the fairly small number of salient variables mentioned in Section 1.2. The assumptions used for the following economic analysis are outlined in the tables and in Appendix E. The alternative fuel is assumed to replace gasoline in the light/medium vehicles and diesel fuel in the heavy trucks and urban buses.

2.7.4.1 The Vintage of the Vehicle or Vehicles Being Converted and the Condition of Its Engine

The age of the vehicles being converted or adapted for natural gas, the condition of their engines, and the quality of the carburetion equipment and equipment installation in general greatly affect the financial value or costs attributed to converting to natural gas or other alternative fuels.

The average number of kilometres (km) travelled by personal-use passenger cars during 1988 was 17 380 km. Models from 1987 averaged 21 290 km annually, with previous model year cars being driven an average of 16 940 km.²⁰ The average fuel consumption per unit of distance travelled was 12.0 litres per 100 kilometres (L/100 km), with 1987 models consuming 10 litres per 100 kilometres and previous model cars, back to and including 1979, consuming an average of 12.04 litres per 100 kilometres. Models older than 1979 averaged 16.6 litres per 100 kilometres.²¹

The average annual distance travelled by a vehicle and the volume of fuel consumed in doing so greatly affect the value of a conversion. The savings received by the vehicle's owner, and hence the time required to recover the cost of conversion, is directly dependent upon the price differential between natural gas and gasoline or diesel fuel and on yearly fuel consumption.

2.7.4.2 The Price Differential or Market Value of the Fuel in Relation to Gasoline or Diesel Fuel

Currently, natural gas benefits from a 25 cent per litre equivalent differential when compared to gasoline and a 15 cent per litre equivalent differential when compared to diesel fuel. This average national price differential varies greatly across the provinces, however, depending on provincial supply and/or proximity to alternate supply sources. Obviously, all else being equal, the greater the price differential in favour of natural gas, the better the economics of converting.

From Table 2.6 and Figures E.1 and E.2 one can recognize the advantage which persons converting light/medium vehicles to natural gas in British Columbia (29 cents per litre equivalent differential) would have over people converting in Quebec (19 cents per litre equivalent differential) where natural gas enjoys a smaller price differential advantage from regular unleaded gasoline (see Table D.1). These price differentials are representative of those provided in July 1990 in a retail price survey supplied by the Canadian Gas Association, and are subject to change. Although the price differential between natural gas and diesel fuel is 10 cents per litre equivalent less than the differential between natural gas and gasoline, and the pessimistic light/medium conversion costs (\$3200) are the same as the optimistic heavy vehicle costs, the higher mileage heavy vehicles of the smaller delivery truck size can pay off their costs in less time than light/medium vehicles because they drive farther annually and consume greater volumes of fuel, thus accruing greater savings (see Figures E.3 through E.5).

2.7.4.3 The Conversion Costs

Conversion costs vary depending on the conversion kit being applied, where the conversion is taking place (by the OEMs or by private conversion shops), the kind of vehicle being converted (light/medium vehicle, heavy truck, bus), the number of fuel cylinders involved, and the labour costs. An additional consideration is the likely potential for economies of scale when converting commercial fleets rather than personal passenger vehicles. The conversion costs being utilized in this analysis are outlined at the beginning of Appendix E. Increasing conversion costs from \$900 (which is an estimated cost of conversion should the OEMs move to commercial sales volumes and only add the incremental costs attributed to the

TABLE 2.6
EFFECTS OF PRICE DIFFERENTIAL
ON PAYBACK OF CONVERSION COST

	Life (years)	Conversion Cost Base Case (\$)	km/yr	Le/1000 km	Price Differentials (¢/Le)	Payback (years) ^a
L/M Personal Vehicles ^b	5	2,800	20 000	125	20 25 30	8 5.9 4.6
L/M Fleet Vehicles ^b	5	2,800	75 000	125	20 25 30	1.6 1.3 1.0
Heavy Vehicle > 3855.6 kg ^c	7	3,700	40 000	350	10 15 20	3.0 1.9 1.4
Heavy Vehicle ~47 000 kg ^c	7	22,500	70 000	460	10 15 20	11.5 6.2 4.3
Urban Bus ^c	16	35,000	50 000	530	10 15 20	>30 20.2 10.4

SOURCE: Canadian Energy Research Institute.

^aThe fuel savings calculated to determine the payback were discounted mid-year at 10 percent.

^bPrice differential from gasoline.

^cPrice differential from diesel fuel.

natural gas cylinders required) to \$3200, while holding the price differential constant at 25 cents per litre, increases the payout period by approximately 65 months or 5.4 years as can be observed in Figure E.1. Figure 2.10 displays the effect which the current \$500 federal incentive plus the \$1000 provincial incentive in Ontario has on the time it takes to recover vehicle conversion costs. Whereas personal-use vehicles travelling under 20 000 kilometres take around five years to pay off with no incentives, these same vehicles can be paid off in just over a year with the maximum available incentives.

2.7.4.4 The Distance Travelled Annually

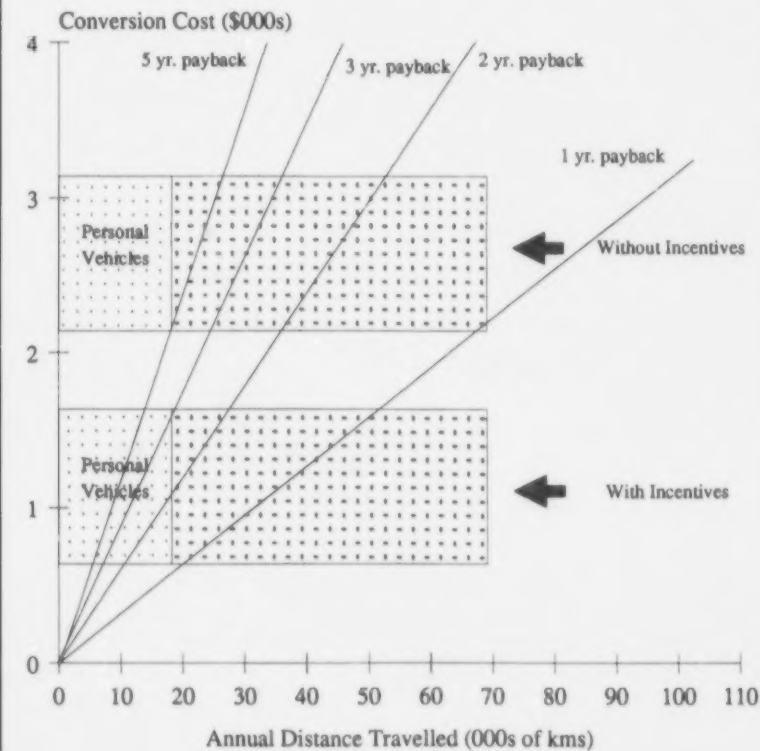
Although the average personal passenger car travels approximately 17 000 kilometres per year, the average taxi and commercial fleet vehicle travels three or more times this distance. Commercial trucks and urban buses in Canada are likely to average 40 000 to 50 000 kilometres annually. Table 2.7 and Figures E.6 through E.9 indicate the effect on payout of these increased vehicle mileages. Though personal-use vehicles do not pay out in the three-year payback period indicated on the graph in Figure E.6, taxis travelling 30 000 kilometres a year and more could pay off the optimistic costs of \$2200 in that time period.

If a taxi fleet manager wishes to repay the costs of converting a fleet (at a base case conversion cost of \$2800 per vehicle) within one year, then without incentives the average distance travelled per vehicle annually would have to be approximately 94 000 kilometres. If the optimistic conversion cost scenario (\$2200 per vehicle) is assumed, the annual distance requirement drops to 73 800 kilometres. When the \$500 federal incentive is deducted from these two cases, the distances required to repay conversion costs are reduced to 77 200 and 57 000 kilometres, respectively. Both of these scenarios assume a constant price differential of 25 cents per litre equivalent. From the analysis it becomes apparent that early market penetration, when conversion costs are at their peak, will necessarily be aimed at the fleet market.

2.7.4.5 The Type of Operation: Single Vehicle, Small Commercial Fleet, or Large Commercial Fleet, and the Compressor or Fuelling Station Costs

The importance of fleet size becomes apparent when the costs of refuelling facilities are considered (see Figures 2.11 through

Figure 2.10
Payback Based on Conversion Cost and
Distance Travelled for L/M Vehicles



SOURCE: CERL.
NOTE: Price differential from gasoline = 25 cents/L.e.
 +  = Fleet light/medium vehicles.

TABLE 2.7
LIFETIME FUEL SAVINGS FROM
NATURAL GAS CONVERSION

Assumptions			Conversion Costs (\$)		Fuel Savings (\$)		Net Benefit (\$)	
L/100 km	km/yr	Life (years)	Optimistic	Pessimistic	Discounted (10%)	Optimistic	Base	Pessimistic
L/M Personal Vehicles ^a	12.5	20 000	5	2,200	2,800	3,200	2,485	285 (315) (715)
L/M Fleet ^a	12.5	75 000	5	2,200	2,800	3,200	9,318	7,118 6,518 6,118
Heavy Vehicle > 3855.6 kg ^b	35	40 000	7	3,200	3,700	4,200	10,723	7,523 7,023 6,523
Heavy Vehicle = 47 000 kg ^b	46	70 000	7	20,000	22,500	25,000	24,662	4,662 2,162 (337)
Urban Bus ^b	53	50 000	16	20,000	35,000	50,000	32,617	12,617 (2,383) (17,383)

SOURCE: Canadian Energy Research Institute.

NOTE: Net benefits do not include any infrastructure costs.

^aPrice differential from gasoline is 25 cents per litre equivalent.

^bPrice differential from diesel fuel is 15 cents per litre equivalent.

Figure 2.11
Leased Home Compressor Viability
Light/Medium Vehicles

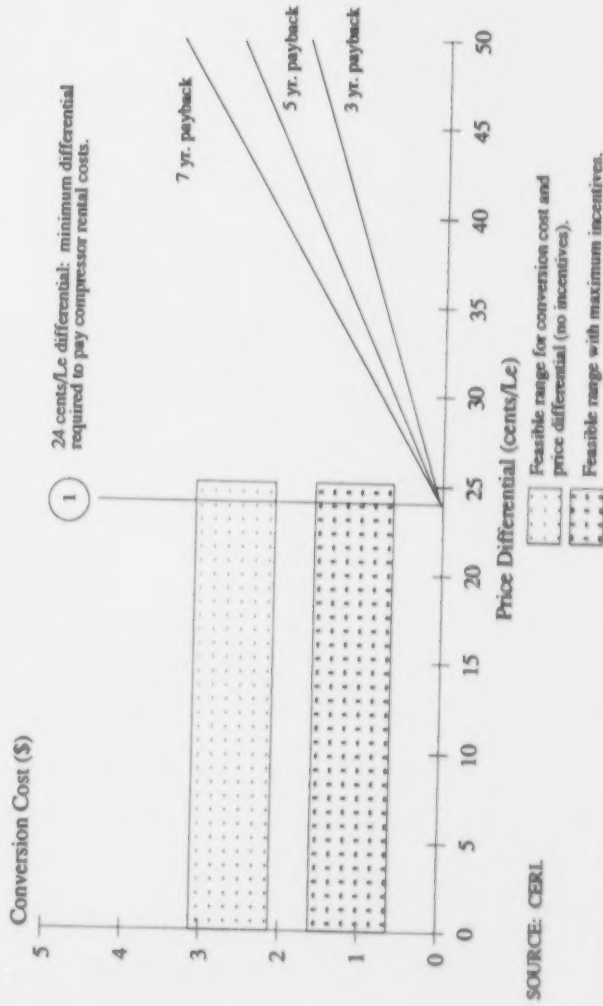


Figure 2.12
Two-Car Leased Home Compressor Viability
Light/Medium Vehicles

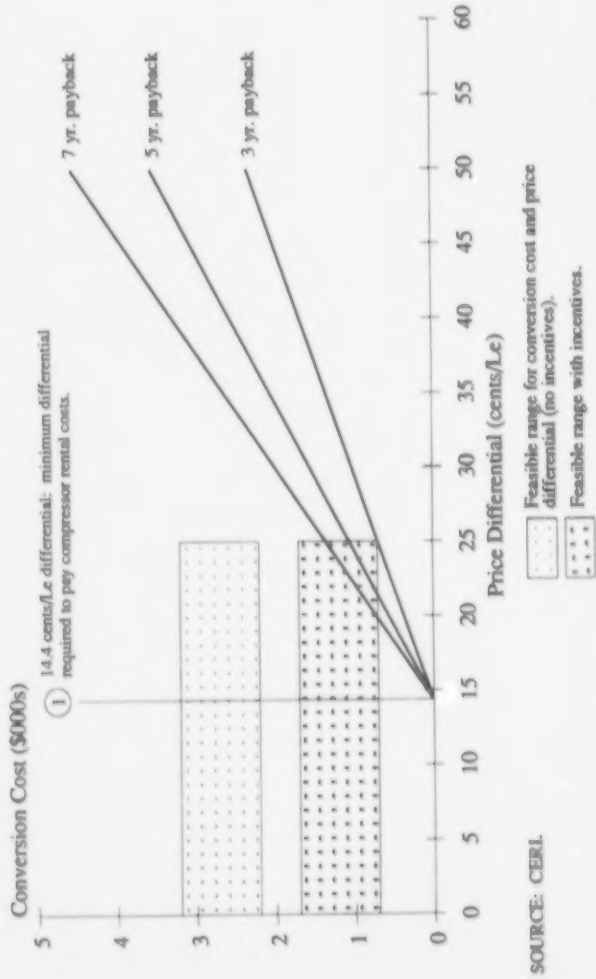
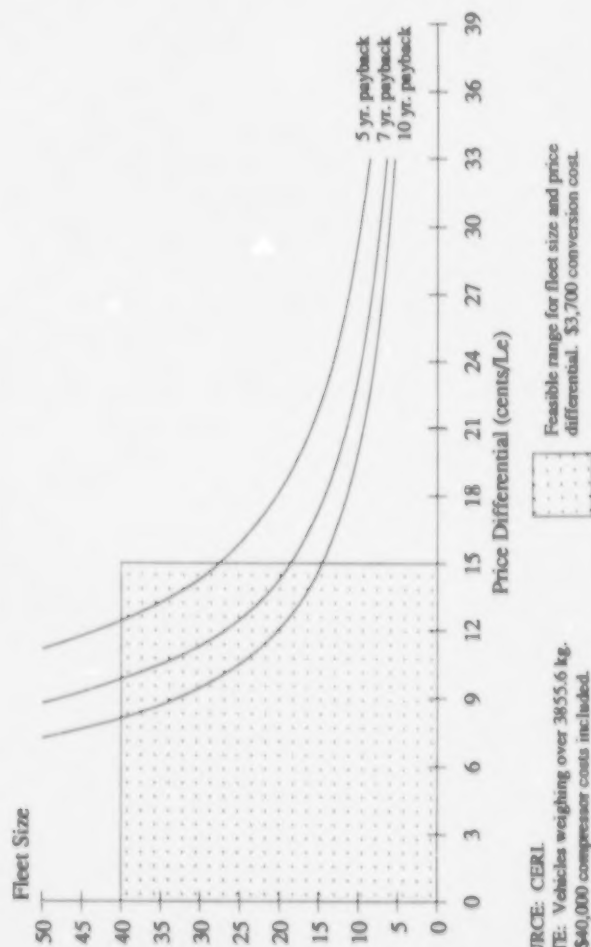


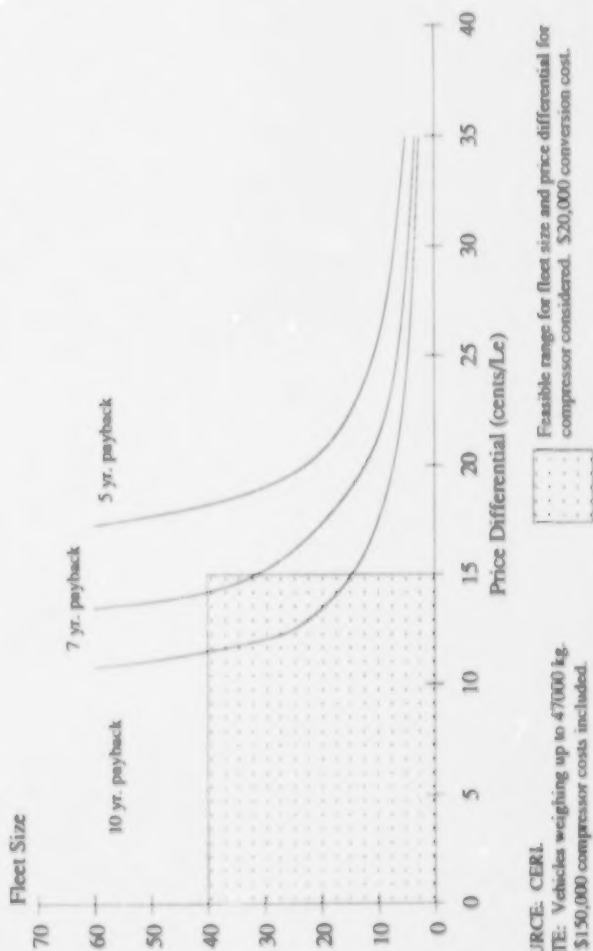
Figure 2.13
The Effect of Fleet Size on NGV
Heavy Fleet Viability



SOURCE: CERI.

NOTE: Vehicles weighing over 3855.6 kg. and \$40,000 compressor costs included.

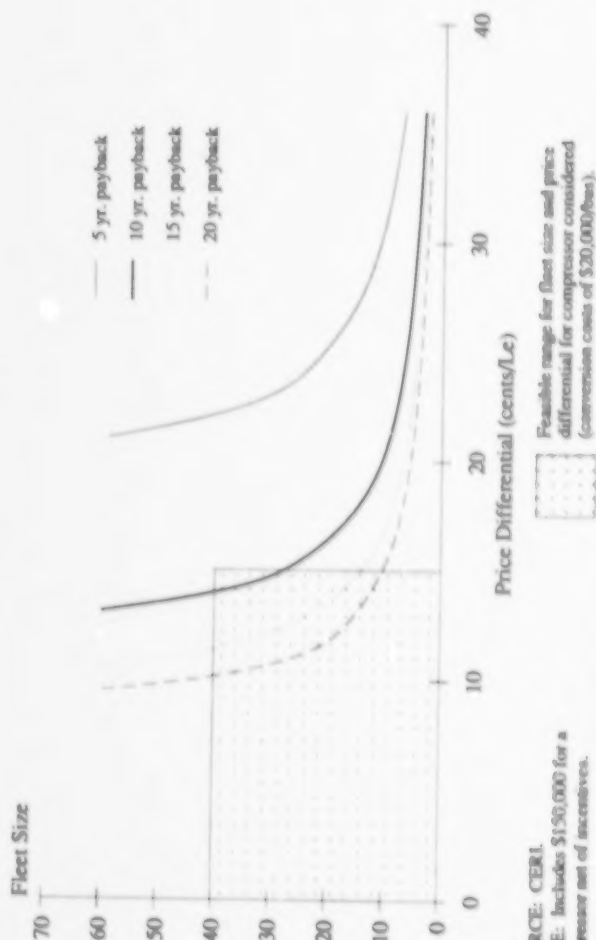
Figure 2.14
The Effect of Fleet Size on NGV
Heavy Fleet Viability



SOURCE: CERL

NOTE: Vehicles weighing up to 47,000 kg. and \$150,000 compressor costs included.

Figure 2.15
The Effect of Fleet Size on NGV
Bus Fleet Viability



SOURCE: CERL.
 NOTE: Includes \$150,000 for a compressor net of incentives.

2.15). For one car to recover the cost of conversion plus a home compressor in two years (including incentives), the car must travel just over 49 000 kilometres annually. However, in order for two cars to recover the costs of their conversions and a home compressor large enough to supply their refuelling needs within two years, each car must travel just over 34 000 kilometres annually.

While it may appear that the larger the vehicle or numbers of vehicles being fuelled, the larger is the compressor required, and therefore the longer is the time necessary to recover its cost, this is not necessarily the case. While larger compressor requirements involve greater capital outlays, the very fact that more fuel is being consumed means that larger compressors have their costs spread out over a greater fuel volume. Thus, if economies of scale are exhibited by compressor costs, larger compressors may actually be paid off in less time than smaller refuelling devices. However, it is true that if very high maximum rates of refuelling are desired, then payoff periods will be lengthened, since the type of refuelling appliance utilized (slow-fill or fast-fill) greatly affects initial investment costs and ultimately the requirements which must be met in order to pay it off. For instance, a fast-fill refuelling station designed to fill a bus carrying approximately 227 litres of fuel in under five minutes would currently cost in the range of \$3 million dollars. A station designed to fill a bus in ten minutes would cost less than half that. A slow-fill station designed to fill the same bus in 45 minutes would cost around half a million dollars (see Figure E.10).²²

The effects which the additional burden of including the refuelling facility costs have on the economics of bus fleet conversions can be observed in Figure 2.15. It is important to recognize, however, that the refuelling facility costs used in the analysis reflect costs from public and confidential documentation as well as "pilot" projects currently being developed or in operation. These costs reflect a technology that has not gone through the familiarization stage and include much of the up front research and development costs that in the longer term would be greatly diminished. Station costs will also vary for a number of other reasons, including the number of vehicles being serviced, the remoteness of the station reflecting the distance from the fuel supply, safety and redundancy costs, and whether the station is a regular retail station, a truck stop or a station designed for a particular vehicle fleet.

2.7.4.6 The Volume of Fuels Being Consumed and Distillate Being Displaced

The greater the volume of natural gas ultimately consumed by natural gas vehicles, whether dual-fuel or mono-fuel, the sooner the payout will be reached (see Figures 2.16 through 2.20). Mono-fuel vehicles would have an advantage over dual-fuel vehicles under these conditions, as the mono-fuel vehicles would consume more natural gas or displace more distillate over the same driving range.

As noted from Figures 2.16 and 2.17, high mileage vehicles such as taxis and commercial trucks consume the greatest volumes of fuel, and so pay off relatively quickly in comparison to personal vehicles. Urban buses travelling 50 000 kilometres annually are also capable of recovering their costs in a reasonable time considering their average vehicle life of sixteen years (see Figure 2.19). The alternative fuel must, however, be priced in a manner whereby it achieves a large enough positive differential between itself and gasoline or diesel fuel to assure the consumer that he will achieve savings sufficient to recover his costs within a reasonable time period.

2.7.4.7 Incentives and Subsidies

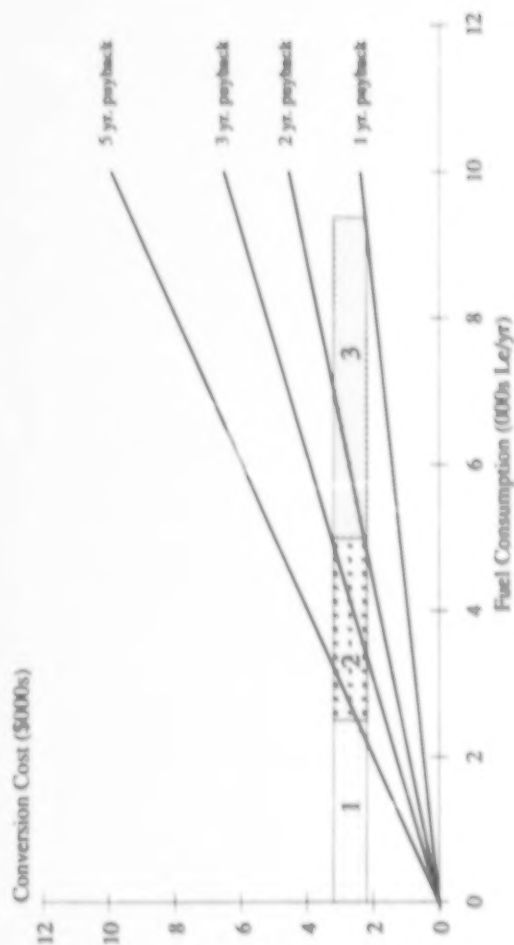
Incentives and subsidies greatly affect the viability of converting to natural gas. The \$500 federal conversion grant (with a 25 cents per litre equivalent differential between natural gas and gasoline) is currently equivalent to approximately 2000 free litres of natural gas or 16 000 kilometres travelled free of fuel costs. This driving range is almost equal to the distance an average personal vehicle travels annually. Figures E.11 and E.12 indicate the comparative subsidies and price incentives required to repay conversion costs in a specific time period or annual distance travelled. Figure E.13 indicates the effect of current incentives on the payback period.

2.8 Technological Advancements

Until recently, marketing activities have concentrated on opportunities for NGV to substitute for gasoline. Research and development efforts have been directed at methods of improving the performance of available NGV dual-fuel conversion equipment for gasoline engines to ensure compatibility with the new engine designs equipped with electronic fuel management systems.

Research by companies such as Powertech Labs in Vancouver to develop lighter, less costly storage cylinders that meet

Figure 2.16
Payback Based on Conversion Cost and
Fuel Consumption for L/M Vehicles



SOURCE: CERL

NOTE: No station costs included.

- 1 - Typical personal vehicle fuel usage & conversion costs.
- 2 - Typical commercial vehicle fuel usage & conversion costs.
- 3 - Typical high mileage taxi fuel usage & conversion costs.

Figure 2.17
Payback Based on Conversion Cost and
Fuel Consumption for Heavy Vehicles

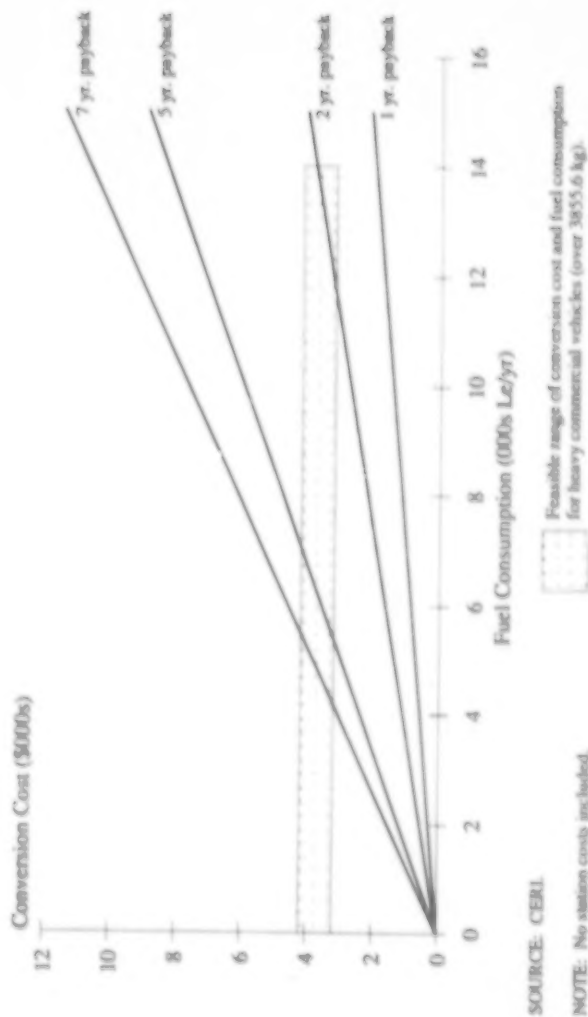


Figure 2.18
Payback Based on Conversion Cost and
Fuel Consumption for Heavy Vehicles

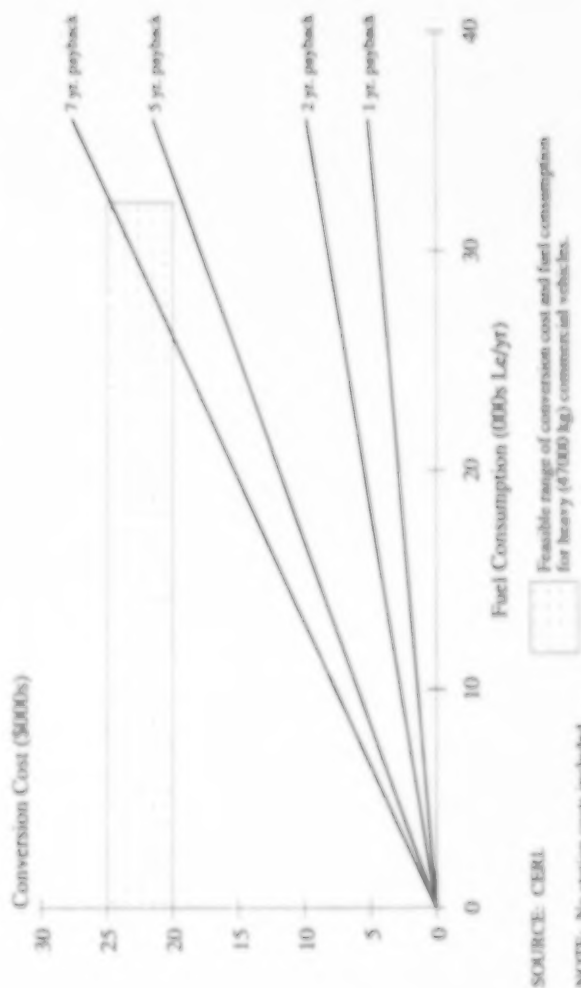


Figure 2.19
Payback Based on Conversion Cost and
Fuel Consumption for Urban Buses

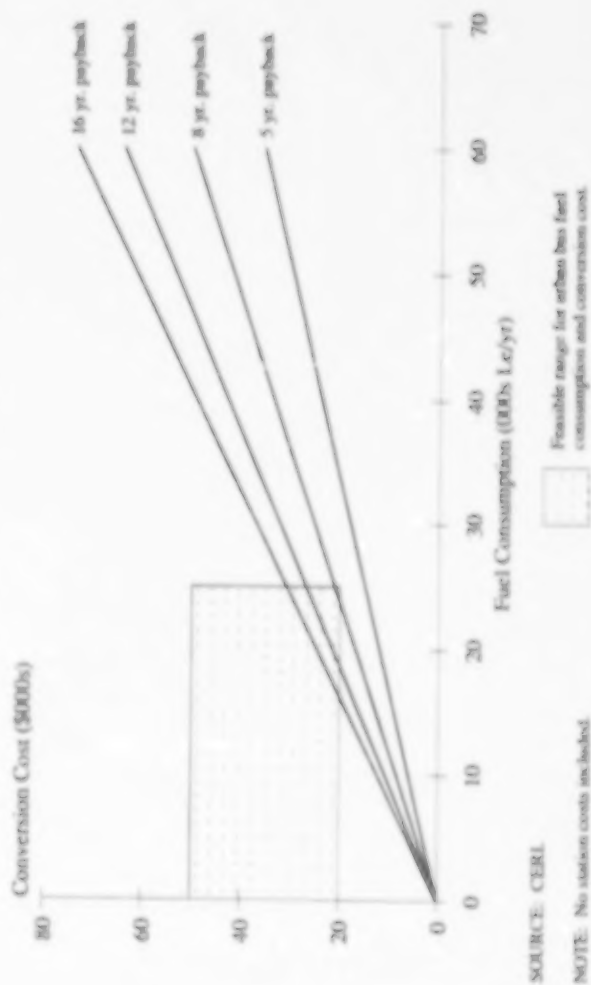
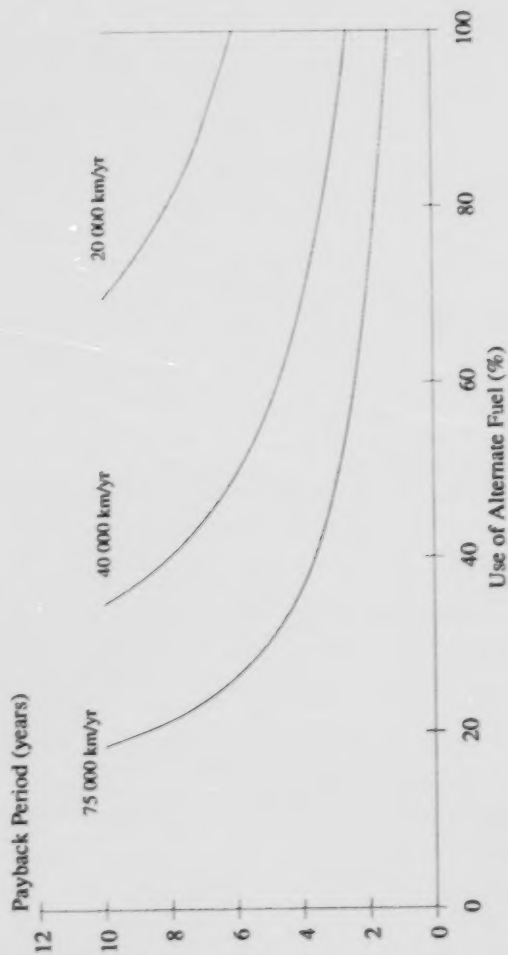


Figure 2.20
Effect of Varying Fuel Consumption on
Payback Period for L/M Vehicles



SOURCE: CERL.
NOTE: Light/medium vehicle, base case
conversion costs.

the required safety standards is necessary in order to overcome the drawbacks of space consumption and added weight associated with carrying a separate set of natural gas cylinders in addition to a gasoline tank. Since fuel economy is inversely proportional to increases in vehicle weight,²³ any reduction in added weight will improve the economic payout period of natural gas vehicles.

Currently, methods of advanced adsorbent fuel storage mechanisms (i.e., carbon inserts in fuel tanks which would allow more fuel to be carried in less space) are being considered as they may increase the range achievable by dual-fuel automobiles and light trucks. Optimizing performance while at the same time reducing emissions is a must if NGV is to gain market demand.

Mono-fuel natural gas vehicles, on the other hand, must balance their potential economic and environmental benefits against the limited availability of refuelling facilities. Recognizing this as a major obstacle to efforts aimed at increasing the demand for natural gas as a vehicle fuel, research efforts have been directed towards ensuring the availability of a safe, economically viable home compressor for overnight refuelling. Fuel Maker Corporation, the manufacturers of the Vehicle Refuelling Appliance (VRA), a small compressor designed in Switzerland, recently announced that they will have the certified home compressor unit available in the market-place (June 1990). This will be a positive step towards bridging the problems related to the lack of a refuelling infrastructure. The VRA compresses the gas to 3000 pounds per square inch, enabling an NGV carrying two 70 litre cylinders of compressed natural gas, equivalent to 45 litres of gasoline, to travel approximately 250 kilometres.

Although market research has indicated that the home compressor will accelerate the demand for NGV in both the private and small commercial markets, the compounded cost constraints (\$3000 per refuelling appliance plus the \$2200 to \$3200 for conversion) will tend to limit the VRAs to high mileage vehicles until demand results in lower costs. Another concern requiring further investigation is the effect that the use of home compressors will have on home heating costs. Optimizing public refuelling station design may prove much more cost efficient. B.C. Gas International has recently begun marketing this type of technology.

Research and demonstration project results for NGV use in large engines such as diesel buses, agricultural equipment and heavy-duty trucks continue to look favourable, especially when comparing

exhaust emissions. The Hamilton Street Railway Company in Ontario currently operates six four-stroke, spark-ignition NGV buses in its fleet of 262 buses. This natural gas diesel demonstration program, which began in 1985, is funded by the Railway, Energy, Mines and Resources Canada, the Ontario Ministries of Energy and Transportation and Communication, and Union Gas Ltd.

The buses, equipped with spark-ignition diesel engines from Italy which were modified in Switzerland to operate on natural gas, have seven NGV cylinders attached to their undercarriages, providing a range of 386 kilometres (240 miles) between refuelling. To provide a comparison of fuel costs and efficiency, as well as emissions, each bus was paired with an unconverted diesel fuelled bus. As natural gas prices, on a price per litre equivalent basis, averaged just over half the price of diesel fuel, fuel cost savings amounted to approximately \$3000 per bus despite the fact that natural gas is 10 percent less efficient. As a result of this economic benefit, the Hamilton Street Railway will be retrofitting an additional four engines to existing buses to bring the fleet up to ten natural gas buses by the end of 1990.

Engine emissions testing indicates that these buses are able to meet the 1991 EPA Transit Bus standards. Results indicated that less carbon monoxide and particulate matter were released from the natural gas vehicles than from their diesel burning counterparts, but that higher levels of hydrocarbons and nitrogen oxides were emitted. Also of note is that the NGV buses were not only quieter and ran more smoothly than the diesel buses but they excelled when climbing the hills in the suburbs of Hamilton.

Other similar projects are in the process of getting underway. Toronto, with three NGV buses currently operating in its city fleet, is looking to test 25 NGV buses manufactured by Ontario Bus Industries of Mississauga and equipped with L-10 Cummins engines. Mississauga is also testing an L-10 Cummins in a transit bus with goals of expanding to a pilot fleet of ten buses.

The Adams Natural Gas Diesel Demonstration Project²⁴ funded by the Enerdemo Canada Program, provided useful comparative data regarding the viability of fuelling and operating diesel road vehicles on dual-fuel natural gas/diesel under commercial operating conditions. This program involved:

- (1) Construction of a natural gas fuelling station at the Adams fuelling station site in Burnaby, B.C., plus

installation of a fuelling station at Cache Creek, B.C. by B.C. Gas Inc;

- (2) conversion of a Safeway Canada Limited truck to a natural gas/diesel operation by Cummins using the Cryogas System (Cummins also provided ongoing technical support); and
- (3) the collection of quality data on a natural gas/diesel truck versus straight diesel operations.

The response to the conclusions arising out of this project have initiated improvements in increased fuelling time and efforts to improve accelerator response problems.

Emissions testing to date indicates that substantial reductions of CO and NMHCs can be achieved from increased usage of dedicated NGV vehicles. An area requiring and receiving more research, development and demonstration is the control of NO_x emissions. Dual-fuel vehicles do have the potential to provide CO reductions, but the magnitude of the reduction is dependent on the ability to maintain low CO calibrations. Trade-offs will undoubtedly be necessary, but it seems likely that emissions levels can be optimized so as to provide environmental benefits.

Significant usage of natural gas in fleet operations in Canada with well trained operators and refuelling attendants has proven NGV to be a safe fuel. Continued scrutiny of product safety, as with all vehicle fuels, will be necessary as NGV becomes more widely used by the general public.

Economically viable and optimized dedicated natural gas vehicles will need further attention from the OEMs in order to attain the performance, fuel economy and emissions requirements necessary to assure regulatory and consumer satisfaction. Definite weight benefits could be achieved if the OEMs were willing to integrate the fuel tanks and supporting structure into the initial vehicle design. General Motors, in an effort to become the first major automaker to produce a fleet of natural gas powered vehicles, will produce approximately 1000 natural gas burning trucks in 1991. These vehicles are to be built at GM's plant in Troy, Michigan, and converted to natural gas by PAS INC., a Detroit supplier. This project entails a joint partnership between GM and a consortium of pipeline and local distribution companies. The vehicles will be backed by a GM warranty, which is a major step towards reassuring the customer of the value of these vehicles.²⁵ Still, it must be recognized that until the

demand for OEM vehicles exceeds the threshold numbers required by the automobile manufacturers, the alternative fuels market will remain an after-sales conversion market. The consumer must ultimately create the demand to which the manufacturers can respond.

The Flexible Corporation, the largest transit bus manufacturer in the United States, as well as Ontario Bus Industries, which both produce buses that utilize the Cummins L-10 heavy-duty diesel engine, will continue to provide dedicated natural gas buses. Much of the initial research into the development of the lean-burn spark-ignition system for the four-stroke engine currently being used in their buses was developed by ORTECH International.

ORTECH International has been developing a Gaseous Fuel Injection System (GFI), which consists of a computerized fuel injection system to control fuel flow and ignition timing, and is adaptable to both gasoline engines (1.0 to 7.5 litres) and diesel engines (50 to 400 HP). Currently, ORTECH is developing a GFI version of the Cummins L-10 diesel engine which will be applicable for use in transit buses, garbage trucks and other intra-city service vehicles.²⁶

Canadian NGV development efforts demonstrate the potential to remove the technical constraints to the market growth of NGV in order to optimize on the economic and environmental opportunities which this fuel presents.

2.9 Conclusions

Natural gas is a clean, non-toxic, plentiful fuel source. The economics of NGV are dependent on the types and numbers of vehicles being converted, their annual mileage, and their fuel consumption. The financial analysis performed indicates that for individual conversions of smaller light/medium size vehicles outside of fleets, NGV economics are very marginal. High mileage fleets definitely have the advantage in this case, because the resulting high fuel use of these vehicles allows larger annual savings to accrue from given price differentials, shortening payoff periods dramatically. With dual-fuel conversions, it is important to recognize that engine efficiency and gas substitution have to be continuous throughout much of the life of the vehicle in order to see any economic benefits.

Increased use of natural gas vehicles in Canadian fleets is consistent with a number of goals currently of concern to this nation: removing lead from vehicle fuels while maintaining appropriate octane

requirements, reducing reliance on imported oil in favour of using a domestic resource, and, probably of foremost concern, the desire to promote clean fuel technology. The conversion rate to natural gas vehicles has tripled since the price of gasoline went over 60 cents per litre in the early stages of the Iraq-Kuwait confrontation in the fall of 1990. Further increases will depend on world oil prices; the speed at which federal and provincial incentives are phased out; safety assurances regarding high pressure storage cylinders; increases in the number of refuelling facilities; and reduction in conversion costs.

Footnotes

¹United States Department of Energy, *Assessment of Costs and Benefits of Flexible and Alternative Fuel Use in the U.S. Transportation Sector*, Progress Report One: Context and Analytical Framework (Washington, D.C.: U.S. Government Printing Office, January 1988), p. 21.

²Canadian Gas Association.

³Rene Moreno, Jr. and D. G. Fallen Bailey, *Alternative Transport Fuels from Natural Gas*, technical paper number 98, Industry and Energy Series (Washington, D.C.: Faber Industries SPA, June 1989), p. 10.

⁴Energy, Mines and Resources Canada, *Natural Gas, An Alternative Transportation Fuel*, Cat. No. M27-71 (Ottawa, Ontario: Supply and Services Canada, 1988), p. 6.

⁵Direct communication with the Canadian Gas Association, December 19, 1990.

⁶Energy, Mines and Resources Canada, Canada Centre for Mineral and Energy Technology, *Cost-Effectiveness of Alternative Transportation Fuels in Urban Bus Operations*, prepared for the Efficiency and Alternative Energy Technology Branch, Energy, Mines and Resources Canada by SYPHER:MUELLER International Inc. (Ottawa, Ontario: Canada Centre for Mineral and Energy Technology, November 1989), p. 52.

⁷*Ibid.*, p. 55.

⁸International Energy Agency. *Substitute Fuels for Road Transportation, A Technology Assessment* (Paris, France: Organization for Economic Co-operation and Development and International Energy Agency, 1990), p. 62.

⁹*Ibid.*, p. 63.

¹⁰*Ibid.*, p. 63.

¹¹United States Environment Protection Agency, *Analysis of the Economic and Environmental Effects of Compressed Natural Gas as a Vehicle Fuel. Volume 2, Heavy-Duty Vehicles*, Special Report (Ann Arbor, Michigan: Office of Mobile Sources, April 1990), p. 3-14.

¹²*Ibid.*, p. 3-16.

¹³Energy Efficiency, Alternative Energy, and Lifestyle Work Group. March 1, 1990, p. 53. Based on an estimated 22,000 natural gas powered vehicles, it was estimated this fleet was reducing non-methanol volatile organic compounds by 710 tonnes per year.

¹⁴James S. Cannon, *Drive For Clean Air, Natural Gas and Methanol Vehicles* (New York, New York: Inform Inc., 1989), p. 112.

¹⁵R. E. Wyman, "Choosing An Alternative Fuel," presented at NGV - The New Direction in Transportation, First International Conference and Exhibition, Sydney, Australia, October 29, 1988, p. 15.

¹⁶For an earlier discussion of the prospects for natural gas vehicle development in the Canadian transportation fuels market, see Brian D. Sumner, *Natural Gas for Vehicles in Canada: A Study of Market Penetration Problems*, CERI Study No. 22, April 1985.

¹⁷National Energy Board, *Canadian Energy, Supply and Demand 1987-2005* (Ottawa, Ontario: Minister of Supply and Services, September 1988), p. 131.

¹⁸Recent updates from the National Energy Board indicate close to a 26 year reserves-to-production ratio for natural gas.

¹⁹United States Department of Energy, *Assessment of Costs and Benefits of Flexible and Alternative Fuel Use in the U.S. Transportation Sector*, Progress Report Two: The International Experience (Washington, D.C.: Office of Policy, Planning and Analysis, August 1988), p. 15.

²⁰Statistics Canada, *Fuel Consumption Survey, 1988*, #53-226, distributed by Household Surveys Division (Ottawa, Ontario: Minister of Supply and Services), p. 157.

²¹*Ibid.*, p. 163.

²²Information supplied by Peter Bigwood of Ontario Bus Industries Inc.

²³United States Environmental Protection Agency, *Analysis of the Economic and Environmental Effects of Compressed Natural Gas as a Vehicle Fuel. Volume 1, Passenger Cars and Light Trucks*, Special Report (Ann Arbor, Michigan: Office of Mobile Sources, April 1990), p. 40.

²⁴This project was initiated in 1986 when John F. Adams & Son Limited (now Christie/Adams Distributor Limited), a commercial truck fuel system operator in Burnaby, British Columbia entered into an agreement with Energy, Mines and Resources Canada.

²⁵"GM, Industry Consortium Plan Natural Gas Fleet," *Natural Gas Intelligence*, June 25, 1990, p. 6.

²⁶Steve Carter, "ORTECH International," paper presented at the 1990 Windsor Workshop on Alternative Fuels, sponsored by Energy, Mines and Resources Canada, U.S. Department of Energy and Ontario Ministry of Energy, Toronto, Ontario, June 11-14, 1990, p. 1.



Chapter 3

PROPANE

3.1 Introduction

The 1979 Iranian oil embargo catalysed Canadian concern for the security of crude oil supply. In response, both the provincial and federal levels of government initiated incentives to encourage greater propane use, both as a heating fuel and as an alternative transportation fuel. A Federal grant program offered motorists \$400 to convert their gasoline-powered vehicles to operate on propane, while Ontario implemented a full retail sales tax exemption. Propane also became exempt from road taxes in a number of provinces. As a result, propane soon became the leading alternative to gasoline and diesel fuel in Canada, particularly for commercial fleets.

Propane is an internationally traded commodity in direct competition with gasoline and #2 fuel oil. Its price, established in North America at only two reference points--Conway, Kansas and Mont Belvieu, Texas--normally ranges from 40 to 60 percent of the price of regular unleaded gasoline. This savings advantage supports the economics of converting high mileage commercial fleets to operate on propane. And yet, this clean burning alternative with excellent operating characteristics continues to struggle to increase its share of the market-place as well as maintain the confidence of the fleet operators who have converted their vehicles to operate on propane. Why is this the case?

Over the past few years, propane's position in Canada has generally been one of excess supply, which has allowed over 40 percent of each year's production to be exported to the United States and Japan. However, in December 1989 and early January 1990, an aberration in what had become a normal weather pattern resulted in extremely cold weather throughout eastern North America. This increased the demand for propane along with other heating fuels. The ensuing short-term strain on the physical movement of propane limited its availability, affecting both posted and spot prices which increased to as high as 35 cents per litre in some parts of Canada.

The price inflation which occurred was a temporary phenomenon followed by a price softening, which allowed for the readjustment of propane prices back to normal (of note is that average annual propane prices vary significantly across the provinces as is reflected in Table D.1). However, this softening of prices back to average annual levels was short lived. The Middle East crisis, which began in August 1990, caused a rapid increase in crude oil prices and ultimately oil products, including gasoline, #2 fuel oil and propane. Once again, commercial fleet operators using propane to fuel their vehicles were faced with increased operating costs and reduced profits.

The obvious concern to fleet managers operating their vehicles on propane is whether or not their fuel costs have risen and their profit margins declined. Perhaps when considering the advantages of using propane, the question they, as well as operators considering conversion to this fuel, should be asking is "are the opportunity gains from using propane instead of gasoline still available?" In other words, has the price per litre equivalent differential between gasoline and propane decreased or not? If not, the economics of converting and operating a fleet on propane should in fact be as good as they had previously been.

Another constraint which has been detrimental to the expansion of the auto propane fuel industry has been the reduction in support from the major automobile manufacturers. Chrysler Canada Limited discontinued the manufacture of propane fuelled engines in 1988. Ford Motor Company no longer markets the propane car which it produced and marketed between 1982 and 1984,¹ having experienced a decline in demand as well as having recognized the finite supply of this fuel source.

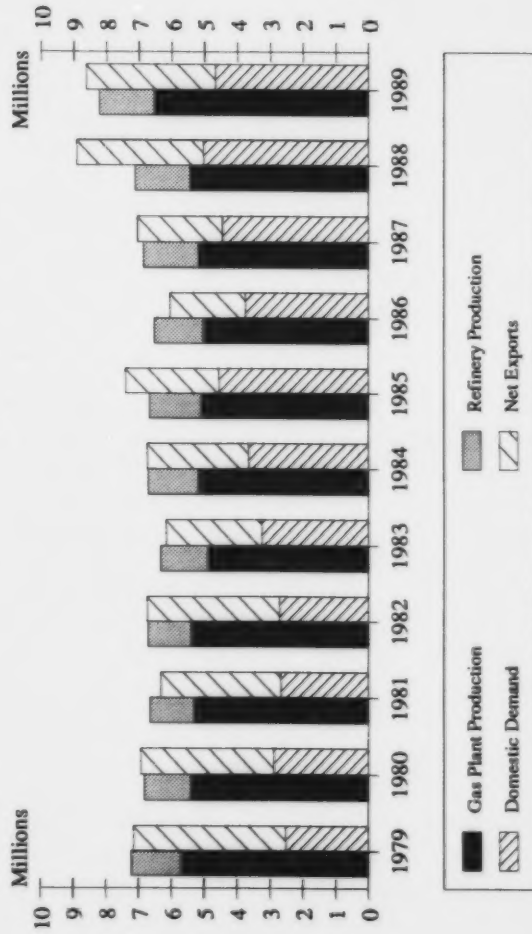
If the propane industry is to continue to increase its market share, progress must be made in the development of new engine technologies and fleet managers must be assured that the free market competitive nature of the business, which has resulted in fluctuating fuel costs, will continue to provide them with economic benefits.

3.2 Technical Assessment

3.2.1 Production Technology

Approximately 80 percent of the current propane supply is a by-product of natural gas processing, while 20 percent is a product of oil refining (see Figure 3.1).

Figure 3.1
Propane Supply and Demand
(cubic metres)



SOURCE: EMR Statistical Handbook.

Natural gas at the wellhead is, as noted in Chapter 2, usually wet. That is, it contains various amounts of heavier condensable hydrocarbons, including propane, which tend to drop out as the chokes at the wellhead decrease the pressure and temperature on extraction. This natural process is continued in the gas plant (see Figure 3.2). Propane can be removed either at the liquid separation stage where the heavier condensable hydrocarbons separate out or by lowering the temperature and removing it at the dew-point stage. As can be seen in Figure 3.2, the propane is then separated out in the hydrogen recovery unit.²

Propane, produced as a by-product of oil refining, is extracted at a number of stages in the refining process (see Figure 3.3). Some propane leaves the fractional distillation unit at the top, while the remainder emerges in later processing of the various hydrocarbon fractions. As propane is produced by the same processes that produce gasoline, the volume of propane produced per cubic metre of feedstock will vary depending on the demands for the product slate as well as the complexity of the refinery.³ Refiners will produce propane to meet the level of demand. Based upon propane projections by the Propane Gas Association of Canada, refiners should be capable of matching anticipated demand volumes over the next ten to fifteen years.

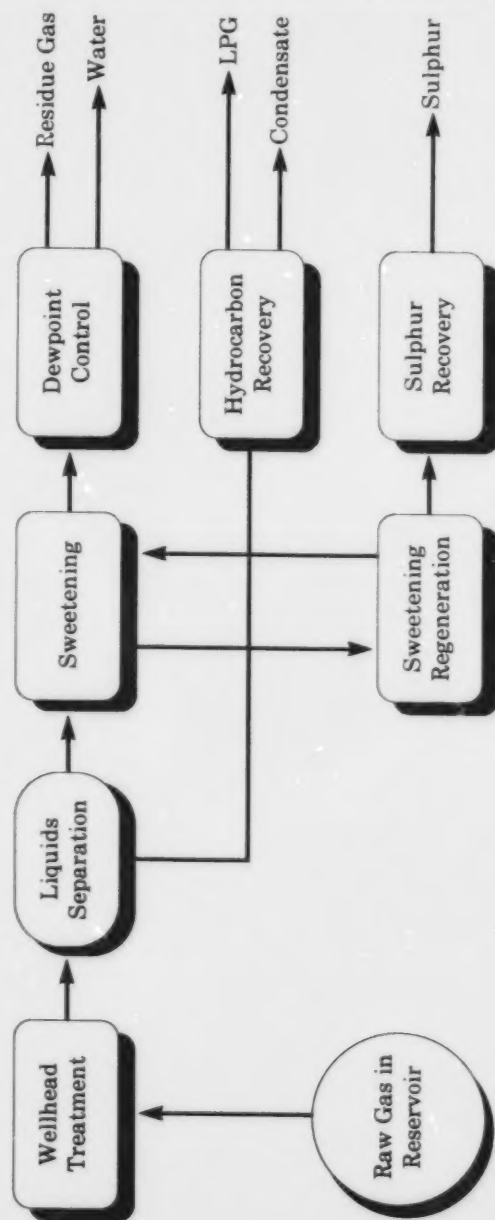
3.2.2 Composition and Characteristics

Propane is a hydrocarbon with a carbon-to-hydrogen ratio below that of gasoline, giving it both a higher octane rating and cleaner combustion characteristics than gasoline.

Propane is the main component of liquified petroleum gas (LPG), which also contains other hydrocarbons such as butane and ethane. It is therefore commonly referred to as LPG. Auto-propane is a special grade, HD-5, consisting of no less than 90 percent propane.⁴ Unlike gasoline, propane is in a gaseous state at atmospheric pressure. It typically contains about 70 percent of the energy content of gasoline and 66 percent the energy content of diesel fuel (variations occur depending upon the precise grade of gasoline or diesel fuel being considered). However, it burns more efficiently than these fuels, and therefore conventional engines operating on propane experience only a 5 to 10 percent power loss, a loss which can be essentially eliminated if the engine is optimized to run on propane.

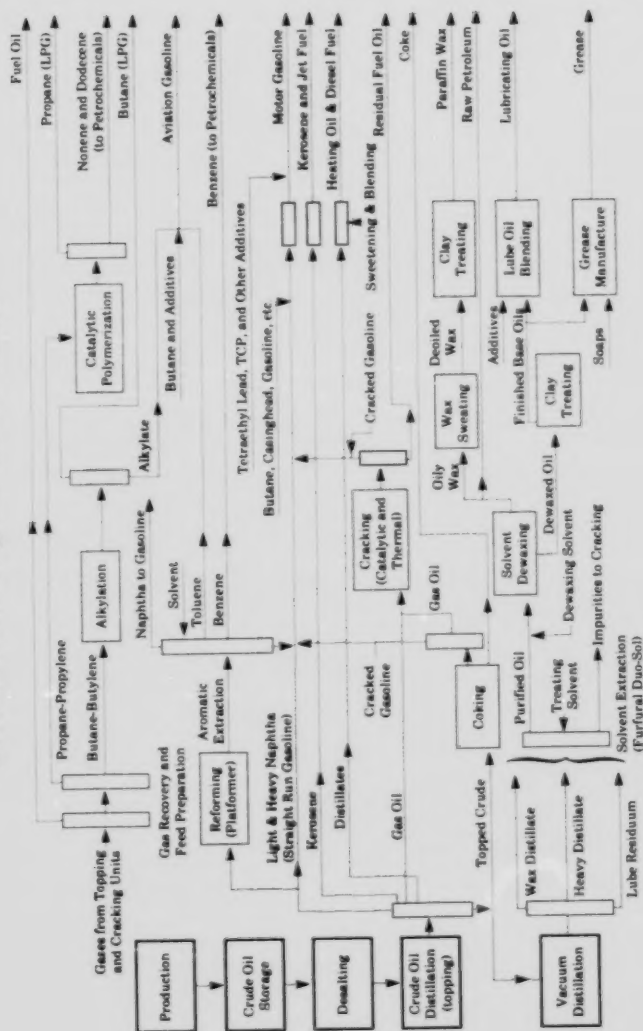
At ambient temperatures, propane for use as a transportation fuel is liquefied at comparatively low pressures and so, unlike

Figure 3.2
Gaseous Fuels



SOURCE: Future Transportation Fuels, Gaseous Fuels, Energy, Mines and Resources Canada.

Figure 3.3
Process Flow Diagram for a Refinery



SOURCE: Texaco, Energy and Economic Database, 1987/88.

natural gas, enough liquid propane can be stored in a relatively lightweight tank to provide a driving range similar to that of gasoline. The vapour pressure of propane varies in relation to the atmospheric temperature. At temperatures of minus 43°C and colder, the pressure in a propane fuel tank is zero and the product is liquid. Although in most countries this would not pose a problem, there are certain times in Canada when the temperature does drop to these levels and propane fuel systems do not operate.

Propane fuel tanks have an excellent safety record. Since the boiling point of propane is lower than that of either diesel fuel or gasoline (see Table A.1 for details of the chemical and physical properties of propane), precautions have been taken to ensure that the tanks have been tested at pressures as high as 265 psi, which represents a substantial safety margin.

Propane's boiling temperature, minus 42°C versus gasoline's boiling range of 25 to 210°C, also has its advantages. Propane's higher volatility allows the fuel to enter an engine's intake manifold as a gas instead of a liquid requiring engine heat to vapourize. The fuel is therefore distributed to the cylinders more evenly, improving engine performance. Propane also has a higher octane rating than either premium or regular gasoline (100 versus 92 and 87, respectively), which allows for higher compression ratios and ultimately better engine performance.

3.2.3 Uses as a Petroleum Substitute

In Canada, propane is principally used as a petrochemical feedstock (in the manufacture of ethylene, polypropylene, antifreeze, rubbing alcohol, etc.) and as a residential, commercial and industrial heating fuel. It is also utilized in certain oil recovery processes as well as for agricultural applications (crop drying and fuelling irrigation pumps).

In addition to these more traditional uses, propane also provides the fuel requirements for over 140,000 vehicles, as noted earlier. Between 1979 and 1985, the annual volumes of this fuel consumed in automobiles increased rapidly. Government incentive programs designed to encourage fuel substitution in response to rising oil prices and concern for oil security supported this growth.

One of the economic constraints faced by propane is that its market share is dependent upon its price, which in turn is determined by its competitiveness with other chemical feedstocks such as ethane, naphtha and gas oil, or other heating fuels (heavy fuel oil, etc.). In recent months the combination of the Middle East crisis and increased environmental awareness on behalf of consumers has generated an upward trend in the number of propane conversions.

3.3 Performance and Compatibility with Current Fuels and the Fuel Distribution System

3.3.1 Compatibility with Current Vehicles

As with natural gas, the physical characteristics of propane are such that modifications to both current vehicle and engine designs, as well as fuel supply systems, are required in order to operate vehicles on propane. These vehicle alterations can be carried out through the installation of propane conversion kits, which are available from conversion equipment manufacturers.

For use in vehicles, propane must be stored under pressures of up to 200 psi to maintain its liquid state. Combined with propane's lower energy density, this necessitates the addition of heavy gauge steel cylindrical storage tanks holding up to 50 percent more volume than required for gasoline, if driving ranges are to be kept comparable to those achieved with gasoline or diesel fuels. Additionally, propane vehicles experience a space constraint if the tanks are located anywhere in the interior luggage or passenger areas; this may result in the reduction of maximum net pay loads in commercial buses, trucks, and taxi fleets. The implied weight constraint due to the additional weight of the propane tanks may be largely offset by the lower specific gravity of liquid propane as compared to gasoline (0.51 versus 0.82 kilograms per litre).

Propane has a very high octane rating and is therefore an excellent fuel for high compression ratio engines. As with natural gas, however, propane will not ignite by compression alone. In the dual-fuel mode in diesel engines, diesel fuel is required as an igniter. When used in the mono-fuel mode, propane requires the modification of diesel engines for spark-ignition.

3.3.2 Distribution

Between 1979 and 1986, motivated in part by government policy and incentives, the propane industry developed the basic equipment and refuelling infrastructure necessary to provide consumers with adequate conversion and service locations, as well as refuelling accessibility. By 1988, there were 5024 propane outlets in Canada. Because of the nature of propane (i.e., a low pressurized gas) the dispensing equipment is such that it must be operated by trained personnel and up to now has not lent itself to widespread "self-service".

The refuelling process for propane in Canada is noticeably different from that for gasoline. In some provinces, licensed attendants are required to dispense propane, prohibiting the conveniences of self-service. Also, it is mandated by law that fuel tanks cannot be filled to more than 80 percent of volume capacity, in order to provide room for the propane to expand in response to temperature changes.

As propane is heavier than air, leaks can result in vapour accumulating near the ground, especially in closed spaces with inadequate ventilation. Pressure relief valves are required for propane tanks to ensure safe release of the fuel should the tank be subject to intense heat. Furthermore, a readily detectable odourant is added to propane for vehicle use to aid in the identification of any product leaking.

Compatible fittings for the dispensing nozzle and the vehicle are necessary. Once the dispensing nozzle is secured to the refuelling fitting of the vehicle, the propane transfer pump can be turned on. Opening a valve allows the propane to flow into the fuel tank until a stop valve determines when the tank is filled.

3.4 Vehicle Options

A gasoline engine converted to operate solely on propane can be optimized to provide greater power output as well as better fuel economy. Dual-fuel gasoline/propane conversions, on the other hand, require compromises in order to provide acceptable performance and emissions levels when operating on either fuel. As with dual-fuel natural gas/gasoline vehicles, dual-fuel propane/gasoline or propane/diesel conversions have both advantages and drawbacks. The benefits attached to having a dual-fuel system are:

- (1) it provides the operator with a choice of fuels, allowing him to utilize whichever fuel is less expensive;

- (2) it minimizes the risk of running out of propane when not close to a refuelling facility; and
- (3) it allows the operator to switch to the other fuelling system, should one of them be operating improperly.

The disadvantages of the dual-fuel system are:

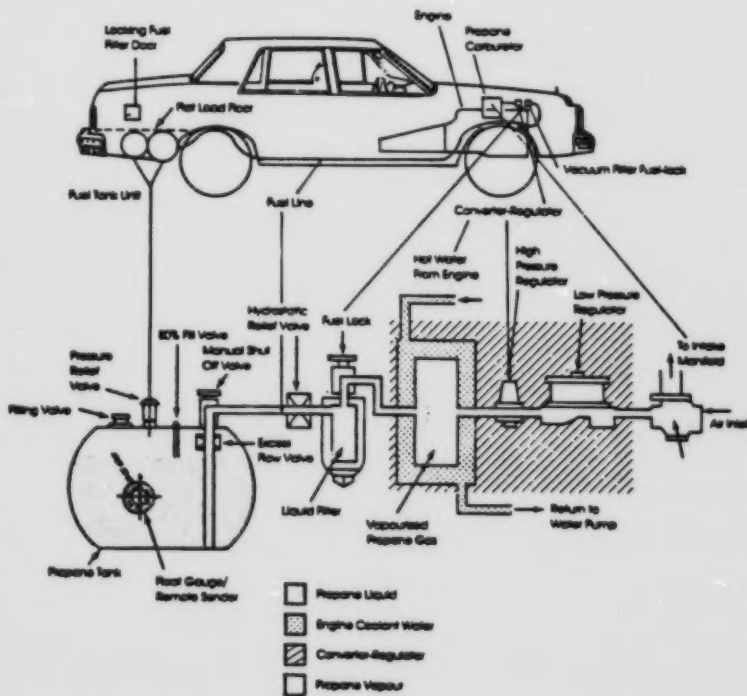
- (1) neither fuel system operates at an optimum level, which reduces fuel efficiency since compromises are made in order to ensure acceptable performance on either fuel;
- (2) it costs more to convert to dual-fuel than to convert to straight propane;
- (3) the added weight of the extra fuelling system reduces fuel economy;
- (4) operating on two systems increases maintenance costs; and
- (5) fuel efficiency is reduced when operating on propane.

The majority of propane vehicles operating in Canada have been converted to operate on propane after having previously operated on gasoline. Indications to date are that a correctly installed propane conversion kit combined with proper engine tuning and maintenance can provide good operating performance and fuel economy.

Conversion of a vehicle to propane requires the installation of a propane fuel system which is suitable for its engine. Modification of the ignition system, as well as air intake and heat control systems, may be required to allow optimum engine operation. As indicated in Figure 3.4, the basic components of a propane fuel system are:

- a heavy gauge pressurized propane tank;
- a fuel lock filter;
- a converter-pressure regulator or vapourizer;
- an air-fuel mixer or carburetor adaptor; and
- added valves, piping and tubing.

Figure 3.4
The Propane-Fuelled Automobile



SOURCE: World Bank, *Alternative Transport Fuels from Natural Gas*.

3.4.1 Propane in Spark-Ignition Engines

Converting vehicles to run solely on propane requires a variety of engine modifications if the combustion characteristics of the fuel are to be fully optimized. Minor changes such as adjustments to the intake manifold, ignition system, and thermostat should be undertaken by a mechanic specifically trained in these conversions.

In a dedicated propane engine, the intake manifold heat riser should be blocked off because propane is already fully vapourized upon leaving the vapourizer/regulator, and therefore does not require the heat which gasoline needs to vapourize on entry to the intake manifold. In fact, if left unblocked, the heated intake manifold would expand the air-fuel mixture, thereby reducing its density and ultimately creating a power loss. Obviously, under a dual-fuel system, blocking off the heat risers would seriously impair the engine's performance while operating on gasoline (see Figure 3.5). This can be corrected by replacing the standard thermostat in the gasoline cooling system with a lower temperature thermostat. The drawback to this is that heat defroster efficiency may be sacrificed.

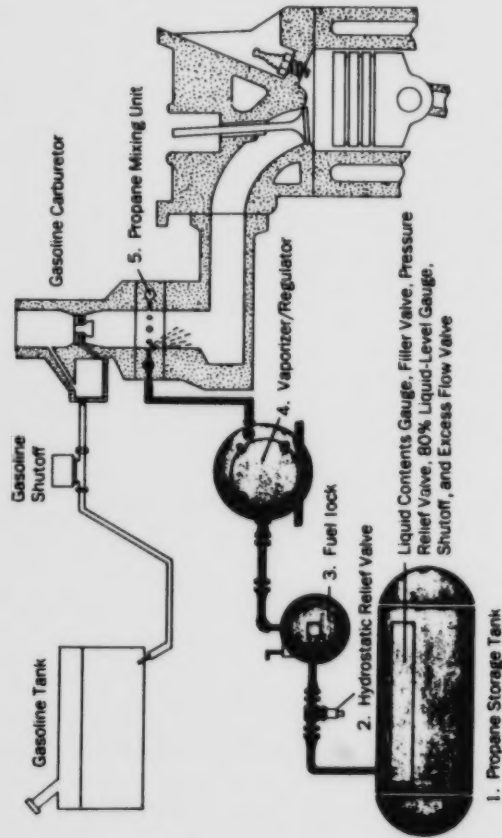
For propane to effectively replace gasoline, the spark-plugs and timing require changes because this fuel's combustion characteristics differ from gasoline. Its higher flame temperature and reduced cooling properties result in higher spark-plug core-nose temperatures, because propane is a vapour in the combustion chamber and does not cool the spark-plug by absorbing heat to vapourize as does gasoline.⁵

Propane's higher octane rating allows the use of compression ratios of up to 13.0:1, as compared to the 8.5:1 ratio which is typical of gasoline engines. Greater power output and better fuel economy result from increasing the compression ratio of an engine, although this in turn can be harmful to the engine's structural integrity.

Ideally, vehicles being converted should also be checked on a chassis dynamometer to determine how far the propane spark curve should be advanced from the gasoline spark curve in order to maximize the potential power of the engine.

With respect to lubrication, the use of propane prior to the phaseout of lead (in leaded gasolines) required hardened valves and seats, since propane is a lead-free fuel and it was the lead which provided the lubrication. However, with impending lead phaseout

Figure 3.5
Schematic of Dual-Fuel Propane/Gasoline System



SOURCE: Alternative Transportation Fuels, Propane, Ontario Energy.

being recognized as far back as the 1970s, engine manufacturers have been using hardened valves and seats so this should no longer be of issue.

3.4.2 Propane in Compression-Ignition Engines

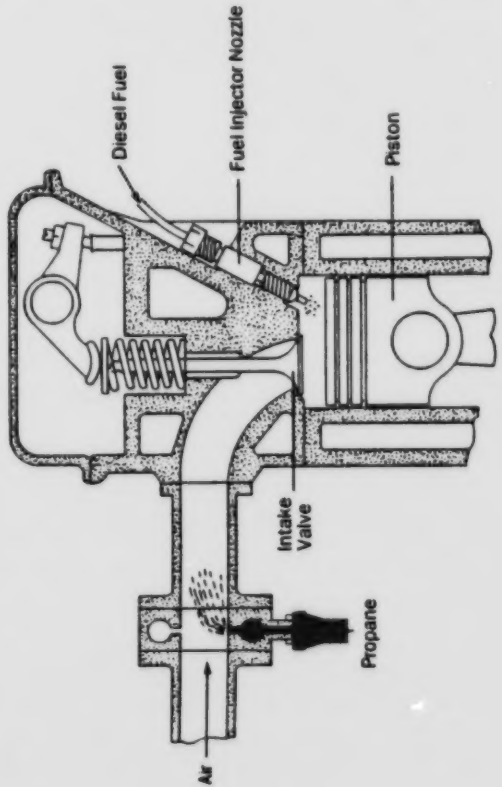
Propane has a very low cetane number and is therefore incapable of pressure-igniting in a diesel engine. There are two techniques for using propane in diesel engines, both of which use diesel fuel to ignite the propane. One method involves feeding propane and diesel fuel into the engine separately, which may be done either by fumigation or dual injection. In the fumigation process, propane vapour is inserted into the air-stream flowing into the cylinder at the same time diesel fuel is injected as in a normal compression-ignition engine (see Figure 3.6). In the dual injection approach, liquid propane and diesel fuel are injected separately into the combustion chambers, the propane supplying the major portion of the energy requirements while the diesel is simply used as a charge to initiate combustion. A second method for using propane in diesel engines involves a homogeneous mixture of propane and diesel fuel. Although the mixture can be formulated to allow for self-ignition under compression, straight diesel fuel may be used during start and part-load conditions, and the homogeneous mixture used under warm, fully loaded conditions.⁶

3.5 Environmental Impacts

Propane is considered a clean burning fuel. The emissions from propane powered vehicles are similar to those operating on natural gas. As propane vehicles have a sealed fuel system, there are no evaporative emissions when the vehicle is either standing or running, unlike gasoline vehicles which can have a significant portion of the total emissions from the vehicle derived from evaporative emissions of the fuel into the atmosphere.

It is important to recognize that emissions testing is a very complex subject, one which requires a complete understanding of the implications of testing a few vehicles under varying conditions in one or more labs. Even tests which are performed on the same engine, in the same vehicle, under the same lab conditions can give results which vary from one test run to the next. Thus, varying the vehicle model being tested or the conversion kit being installed in any way can have extreme effects on test results. In other words, it must be understood when examining the results of any emissions testing that changing any

Figure 3.6
Fumigation



SOURCE: Alternative Transportation Fuels, Propane, Ontario Energy.

one of a great many variables, right down to how often the driver accelerates or brakes the car, will affect the results obtained.

The testing which has been done on propane to date (involving a series of test runs that have been averaged) suggests that, although they are dependent on the air-fuel ratios, carbon dioxide exhaust levels are generally substantially lower than for gasoline. Reactive hydrocarbon emissions are also lower, but nitrogen oxide emissions tend to be higher. Proper equipment and tuning are necessary to provide optimal environmental benefits; otherwise, significantly higher levels of hydrocarbons and nitrogen oxides can result.

A propane emissions test program using the Canadian Motor Vehicle Safety Standards (MVSS), including the Urban Dynamometer Driving Test Schedule (UDDS), was carried out by the Vehicles Emissions Testing Laboratory in Ottawa between September 1989 and April 1990. Two vehicles, a Chevrolet Silverado 5.7 litre V-8 with a dual injector throttle body injection (TBI) gasoline fuel system and a Ford F-150 pick-up truck with a 5.0 litre V-8 multi-point fuel injection (MPFI) system, were converted to propane after emissions data had been collected from the unconverted gasoline engines operating on gasoline (indolene). Table 3.1 summarizes the vehicle specifications. These two cars, in particular, were chosen because they are popular models to convert. The conversion kits installed in them were types that could be acquired in the general market-place. No extras were provided with the conversions, and the cars were simply tuned to specifications.⁷ Each of the vehicles was then tested over a range of operating conditions, including a mix of idle, acceleration/deceleration and steady state conditions, to simulate the normal driving cycle.

As indicated in Table 3.2, at normal temperatures propane fuelled engines can currently meet the gasoline exhaust emissions standards. However, propane, like natural gas, is leaner burning than gasoline and therefore has a higher flame temperature which, as mentioned earlier, usually results in higher NO_x emissions than from gasoline.

Following a test run at 21°C to determine whether the dilution tunnel, the connections to the vehicles, the computers for reading the data and all other auxiliary systems were working correctly, these same vehicles were tested at lower ambient temperatures. The emissions results at temperatures in the cooler ranges averaging between 3.2 and 9.2°C are presented in Table 3.3. The results indicate that in

TABLE 3.1
VEHICLE SPECIFICATIONS AND
DYNAMOMETER SETTINGS

Vehicle	1989 Ford F-150	1989 Chevrolet Silverado
Curb Weight (pounds)	4,078	5,600
Inertia Weight (pounds)	4,500	5,250
Road Load HP	14.5	15.0
Displacement (litres)	5.0	5.7
Fuel System	MPFI ^a	TBI ^b
Number of Injectors	8	2
Transmission	Automatic 4 Speed	Automatic 4 Speed
Emission Controls	EGR ^c Air Injection 3 Way Catalyst Electronic Fuel Injection Electronic Spark Advance Closed Loop System Canister	EGR ^c --- 3 Way Catalyst Electronic Fuel Injection --- Open Loop Canister

SOURCE: Charles S. Dempsey, Propane Gas Association of Canada Inc., "Propane Fueled Engines and the Impact of Decreasing Temperatures on Exhaust Emissions - A Year Round Advantage," paper presented at the 1990 Windsor Workshop on Alternative Fuels, Toronto, Ontario, June 11-14, 1990, p. 3.

^aMPFI - Multi-Point Fuel Injection.

^bTBI - Throttle Body Injection.

^cEGR - Exhaust Gas Recirculation

TABLE 3.2
PGAC OPTIMIZATION PROJECT
 (grams per mile)

Standard	Chevrolet			Ford			
	Indolene	A	B	Indolene	A	B	
CMVSS ^a - UDDS ^b Average <u>Composite Exhaust Emission Rates</u>							
HC	0.8	0.41	0.33	0.42	0.75	1.31	1.01
CO	10.0	3.57	4.61	4.35	1.90	1.12	0.15
NO _x	1.7	0.37	0.75	1.78	1.30	0.84	1.47
CO ₂	no standard	611.17	527.65	511.77	545.10	492.80	478.48
CMVSS - HWFCT ^c Average <u>Composite Exhaust Emission Rates</u>							
HC		0.09	0.08	0.04	0.15	0.55	0.43
CO		1.04	0.72	0.00	0.52	0.49	0.02
NO _x		0.13	0.20	2.03	1.14	0.85	1.45
CO ₂		455.77	381.28	365.67	443.60	386.00	347.77

SOURCE: Charles S. Dempsey, Propane Gas Association of Canada Inc., "Propane Fueled Engines and the Impact of Decreasing Temperatures on Exhaust Emissions - A Year Round Advantage," paper presented at the 1990 Windsor Workshop on Alternative Fuels, Toronto, Ontario, June 11-14, 1990, p. 4.

NOTE: A and B refer to two different types of carbureted fuel systems.

The standard for gasoline fuelled engine exhaust emissions is used, as no standard has been set for gaseous fuels.

Indolene is the standard (gasoline type) fuel used in the certification of gasoline fuelled vehicles to meet the Clean Air Act and EPA requirements for new vehicles.

^aCMVSS - Canadian Motor Vehicle Safety Standard

^bUDDS - Urban Dynamometer Driving Test Schedule

^cHWCFT - Highway Fuel Consumption Test

TABLE 3.3
INDOLENE-PROPANE EMISSIONS COMPARISON
URBAN DYNAMOMETER DRIVING SCHEDULE
TEST SERIES AVERAGE COMPOSITE RESULTS

	HC	CO	NO _x	CO ₂	°C Ambient Start-up Temperature
Standard (g/mile)	0.8	10.0	1.7	No Std.	
<u>Ford F-150</u>					
Indolene	1.62	16.80	1.12	579	7.5 (Average of 6 Runs)
Propane	1.20	0.04	0.80	555	3.9 (Average of 14 Runs)
Propane Emissions as a Percent of Indolene	74	23	71	95	
<u>Chevrolet Silverado</u>					
Indolene	0.67	10.9	1.1	591	7.7 (Average of 6 Runs)
Propane	0.3	4.67	0.36	561	9.3 (Average of 6 Runs)
Propane Emissions as a Percent of Indolene	44	43	31	95	
<u>Ford F-150</u>					
Indolene	5.77	78.94	1.78	503	8.1 (Average of 6 Runs)
Propane	1.58	0.28	1.46	595	3.2 (Average of 14 Runs)
Propane Emissions as a Percent of Indolene	27	0.35	82	118	

SOURCE: Charles S. Dempsey, Propane Gas Association of Canada Inc., "Propane Fueled Engines and the Impact of Decreasing Temperatures on Exhaust Emissions - A Year Round Advantage," paper presented at the 1990 Windsor Workshop on Alternative Fuels, Toronto, Ontario, June 11-14, 1990, p. 3.

the first 505 seconds of engine operation, propane emits much less non-reactive hydrocarbons, carbon monoxide, carbon dioxide and even nitrogen oxides. The lower NO_x levels are believed observed because the engine has not yet warmed to its maximum temperature.

If propane emissions are generally lower than gasoline in vehicles operating on the simple carburetor systems in each of the test vehicles, then the emissions characteristics of an optimized engine designed and installed by the OEMs to operate on propane could prove to be very positive from an environmental viewpoint. Even so, in 1988 propane was designated a clean fuel by the California South Coast Air Quality Management District because of its clean burning characteristics and immediate availability for use in automotive fleets.

Testing has also been performed on a propane engine for heavy truck applications. In 1982 a project was initiated (managed by the Ministry of Transportation of Ontario (MTO) and funded by the Ontario Ministry of Energy) to develop and test the 350 hp spark-ignited, turbo-charged and aftercooled Cummins "Big Cam" propane engine for a class 8 truck application.⁸

The testing involved modifying two diesel engine blocks to operate on 100 percent propane using the spark-ignition concept as propane, with a relatively high octane, lends itself readily to spark-ignition but not to compression-ignition. The engine type selected for converting was the Cummins NTC in-line six cylinder, which displaces 14 litres (855 cubic inches). Full documentation regarding fuel economy, oil consumption, maintenance, driver's comments and engine refinement proved the project, which ended in 1989, to be a success. A number of the conclusions provided in a paper entitled, *Development and Demonstration of a Class 8 Propane-Powered Truck*, written by Jeffery E. Turner and Toros Topaloglu of the Ontario Ministry of Transportation and Gary S. Hrynyk of ICG Propane Inc. were as follows:

- (1) The two propane engines provided reasonable reliability and fuel economy. Over 350 000 kilometres, the two propane engines provided an average 94 L/100 km relative to 45 L/100 km with diesel.
- (2) Engine power was found to be comparable to or better than that of the diesel engine. So also were engine noise and vibration, likely because of the characteristically shallower pressure rise of the spark-ignition cycle.

- (3) Problems encountered, which were considered readily corrected using current technology, involved weaknesses in the turbo-charger, ignition, and cooling systems.

The study also noted that propane engines can potentially meet the strictest United States emission standards regarding not only particulates but CO, HC and NO_x. This will, however, require the refinement of the engine and its accessories plus the development of a suitable catalytic converter. Following these improvements, the engine should be subjected to the EPA transient engine dynamometer test.

3.6 Health and Safety Hazards

Safety standards are provincially regulated in Canada and the current regulations in place for propane are considered among the most stringent in the world. Various standards apply to each component of the propane system, with personnel involved with propane conversion being certified by the applicable provincial authority.

Propane, like natural gas, has been proven through experimentation and exposure to be non-toxic and dangerous only if sufficient quantities are present in a closed space to actually displace the air and cause suffocation. As in the case of natural gas, odourants are added to the fuel to facilitate easy detection should leaking occur.

As propane is denser than air, if there is leaking or a spill, vapour will accumulate near the ground in areas that are not well ventilated. This can be extremely hazardous as contact between a mass of propane vapour and any source of ignition will result in a sudden explosion.

Propane is flammable in air at concentrations ranging from 2.1 to 9.3 percent. These flammability limits are slightly higher than those of gasoline, which is flammable at concentrations ranging from 1.0 to 8.0 percent.⁹

Propane is stored under low pressure. As with natural gas, concerns regarding leaking and explosions have resulted in propane storage tanks being made more secure than storage tanks for gasoline.

3.7 Economic Assessment

3.7.1 Demand

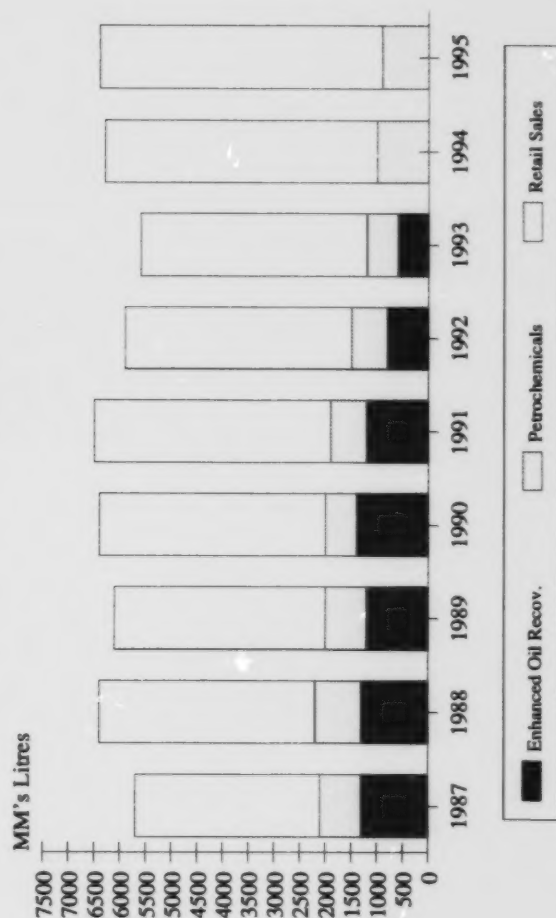
Propane demand from the petrochemical industry and for use in enhanced oil recovery has been relatively stagnant over the past four years. This, coupled with the already existing oversupply, suggests there will be greater volumes available for the auto-propane market. As seen in Figure 3.7, increases in propane demand have been from auto-propane (retail sales) even though the actual numbers of vehicles converted each year has decreased.

The rapid growth of propane demand in the Canadian transportation industry was initially promoted by government incentive programs which, stimulated by rising gasoline prices, were designed to encourage conversion to propane fuel. The result was that the almost negligible quantity demanded in 1979 grew to a figure in excess of one billion litres per year by 1988. However, as can be seen in Figure 3.8, 1984 marked the peak year for propane conversions in Canada, with the number of conversions declining dramatically in the following year.

In 1985, the Federal government removed the \$400 conversion grant available for cars converting to propane. As of July 1989, the province of Ontario, which previously exempted propane from its road tax, imposed a 2 cents per litre tax which further increased by 2.3 cents per litre as of January 1990. Saskatchewan and Alberta have propane taxes of 7 and 5 cents per litre, respectively (see Table D.1). Manitoba continues to apply a 5.7 cents per litre road tax to propane, while Quebec taxes propane at a rate of 8.25 cents per litre.

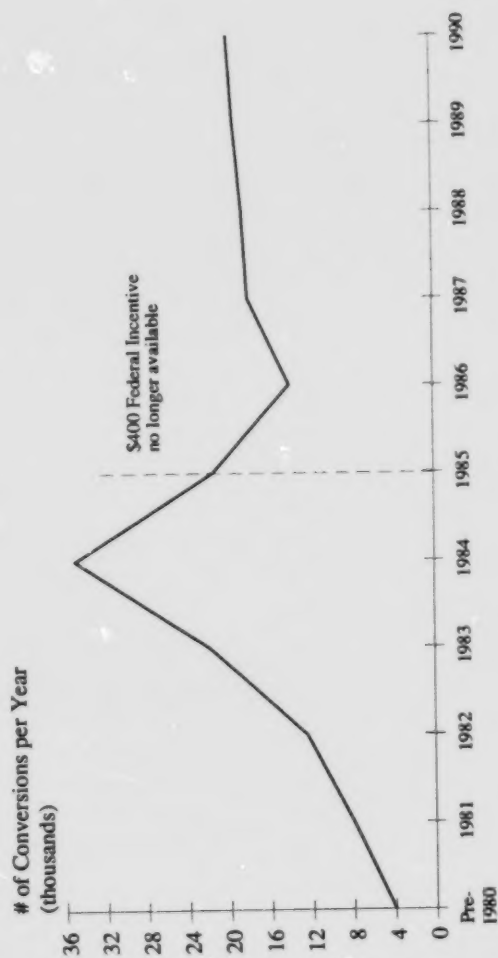
Legislative support for special tax incentives to encourage propane use appears to be waning, with the emphasis now being shifted to an approach which lets the market determine demand. In other words, the incentive to use propane rather than gasoline is becoming one based solely upon the price differential between the two fuels, although increasing recognition of propane's environmental advantages may reverse this trend. Of note here is that although the 1985 drop off suggests that the \$400 incentive was definitely a driving force in the decision to convert to using propane, it was apparently not the only financial advantage to be had from propane conversion. Only 71,000 of the 140,000 propane vehicles on the road at the time the federal incentive program ended had received the grant. Still, the incentive program undoubtedly was a motivating factor for many

Figure 3.7
Total Canadian Propane Demand



SOURCE: PGAC Industry Survey,
March 1989.

Figure 3.8
Auto-Propane Conversions
Annual Rate



NOTE: Peak fleet size: estimated
at 150,000 vehicles.

SOURCE: Propane Carburetion Markets in
Canada, Propane Gas Association of
Canada Inc.

conversions. It not only increased the economic attractiveness of conversion, but was also viewed as a sign of government support for a continued role for propane in the transportation market.

In recent years, conversions have ranged from 15-20 thousand annually although the Gulf crises and rising gasoline prices have once again resulted in an upswing in conversion rates. Unless these conversion rates continue to increase, the total Canadian propane fleet, which has been estimated to have at one time reached 150,000 vehicles, will continue to contract.¹⁰ However, should the fleet size grow to absorb 2.5 percent of the demand for unleaded gasoline and diesel as vehicle fuels by the year 2000, 2 billion litres of propane would be required annually to serve this market.

3.7.2 Supply

As noted earlier in Section 3.1.1, approximately 80 percent of the current propane supply is produced as a by-product of natural gas processing, while 20 percent is a product of oil refining. In 1989, Canada produced 8.3 billion litres of propane, imported 0.3 billion litres and exported 3.8 billion litres. Approximately 1.1 billion litres were used in the transportation industry.

As seen in Figure 3.1, gas plant production has increased over the past couple of years, after having remained fairly constant since 1979. A number of factors have affected the levels of liquids production, including propane sales, processing efficiency, natural gas reserves, and the liquid content of the raw gas being processed. In the immediate future, a number of competing influences will help determine production trends: recovery increases resulting from greater efficiencies are likely to be partially offset by the greater percentage of drier gas being extracted from non-oil associated reservoirs, while the phaseout of lead from gasoline will likely boost the demand for high-octane unleaded fuels, the need for higher processing severity, and hence the refinery production of propane.

The greatest influence on propane production levels is the volume of propane sales. Propane sales have increased over the past couple of years despite fluctuating and relatively low gasoline and diesel prices. Supply levels are ample to provide for domestic requirements, although tight supply situations may arise when unusually cold weather results in rapid increases in the demand for heating fuel supplies. These tight supply situations are usually short

in duration, but they definitely can have immediate and pronounced effects on posted propane prices and consumer sales.

3.7.3 Incentives

Recent legislative initiatives, which are forcing propane to maintain a more competitive position in the market-place, can be misinterpreted as an indication of rejection by the government. The consumer must recognize that the incentive programs, as originally initiated, were designed to act as a catalyst to get the industry started, so that dependence on gasoline and diesel fuel could be decreased. This they did and, although they did not spur propane usage to the extent which was initially envisaged, the incentive programs were instrumental in enabling propane to absorb approximately 2.1 percent of the total gasoline and diesel market.

If the industry is to continue to expand, progress must be made in the development of new technologies and in the growth of new market areas. With this objective in mind, the Canadian government recently allocated another \$1,150,000 to the following programs, which are either ongoing or have been newly implemented:

- (1) The Auto-propane Market Development/Demonstration Program will identify and develop new market potential through selected demonstration programs.
- (2) The Auto-propane Technical Program is intended to support research and development field trials and technical demonstrations towards improvements in the use of propane as an automotive fuel. A major project currently being sponsored by this program is the development of a generic electronic control system for auto-propane.
- (3) The Auto-propane Marketing Program is designed to assist in promoting the fuel across the country.

3.7.4 Empirical Assessment of the Value of Propane

As with natural gas, the key to acceptable propane conversion economics lies with the price differential available, the annual distances travelled and the volume of fuel consumed (see Tables 3.4 and 3.5 and Figures 3.9 through 3.14). Propane proves to be especially well suited for commercial light/medium sized fleet vehicles, in particular those driven over 40 000 kilometres annually (see Figures F.1 through F.4) and using approximately 6200 litres of propane (or

TABLE 3.4
EFFECTS OF PRICE DIFFERENTIAL ON
PAYBACK OF CONVERSION COST

	Life (years)	Assumptions			Price Differentials		Payback Period
		Conversion Cost Base Case (\$)	km/yr	Le/1000 km	ϵ/Le	years ^c	
L/M Personal Vehicles ^a	5	1,800	20 000	125	12 16 20	8.9 5.9 4.4	
L/M Fleet Vehicles ^a	5	1,800	75 000	125	12 16 20	1.8 1.3 1.0	
Heavy Vehicle > 3855.6 kg ^b	7	2,200	40 000	350	6 8 10	3.0 2.2 1.7	
Heavy Vehicle = 47 000 kg ^b	7	12,000	70 000	460	6 8 10	9.4 6.2 4.6	
Urban Bus ^b	16	13,500	50 000	530	6 8 10	17.4 9.2 6.6	

SOURCE: Canadian Energy Research Institute.

^aPrice differential from gasoline.

^bPrice differential from diesel fuel.

^cThe fuel savings calculated to determine the payback were discounted mid-year at 10 percent.

TABLE 3.5
LIFETIME FUEL SAVINGS FROM
PROPANE CONVERSION

Assumptions			Conversion Costs (\$)		Fuel Savings (\$)		Net Benefit (\$)	
L/100 km	km/yr	Life (years)	Optimistic	Pessimistic	Discounted (10%)	Optimistic	Base	Pessimistic
L/M Personal Vehicles ^a	12.5	20 000	5	1,400	1,800	2,200	1,590	190 (210) (610)
L/M Fleet ^a	12.5	75 000	5	1,400	1,800	2,200	5,964	4,564 4,164 3,764
Heavy Vehicle > 3855.6 kg ^b	35	40 000	7	1,800	2,200	2,600	5,719	3,919 3,519 3,119
Heavy Vehicle = 47 000 kg ^b	46	70 000	7	9,000	12,000	15,000	13,153	4,153 1,153 (1,847)
Urban Bus ^b	53	50 000	16	10,000	13,500	17,000	17,396	7,396 3,896 396

SOURCE: Canadian Energy Research Institute.

NOTE: Net benefits do not include any infrastructure costs.

^aPrice differential from gasoline is 16 cents per litre equivalent.

^bPrice differential from diesel fuel is 8 cents per litre equivalent.

Figure 3.9
Payback Based on Price Differential and
Conversion Cost for L/M Vehicles

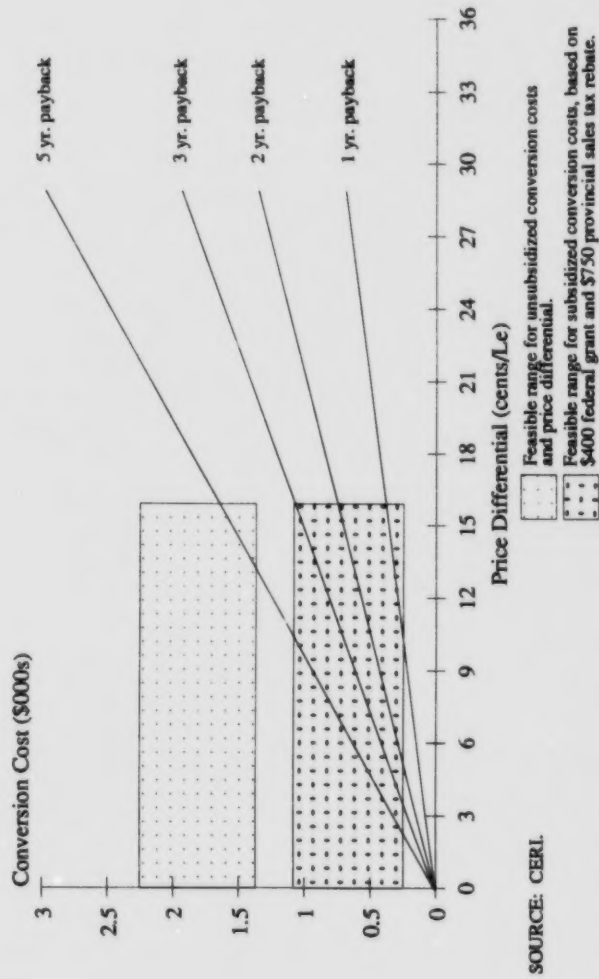


Figure 3.10
Payback Based on Conversion Cost and
Distance Travelled for L/M Vehicles

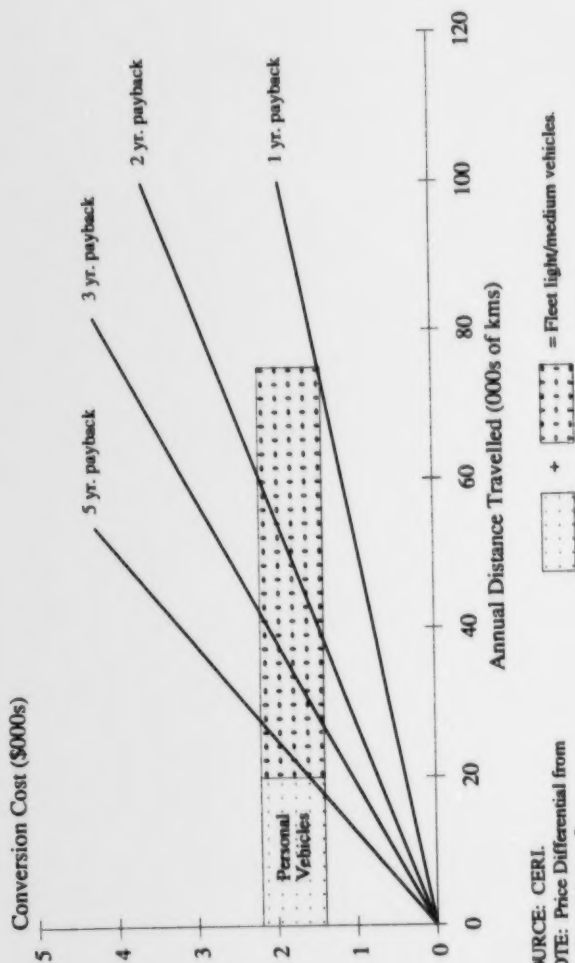
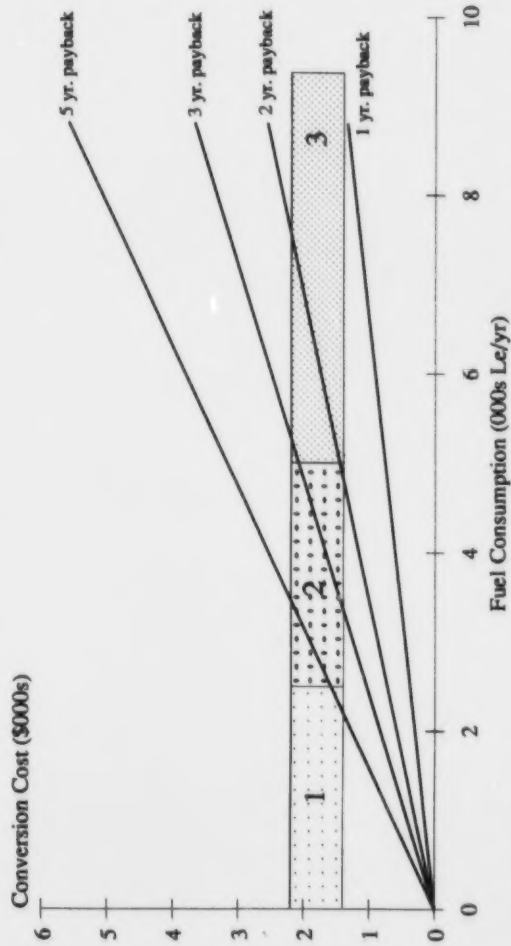


Figure 3.11
Payback Based on Conversion Cost and
Fuel Consumption for L/M Vehicles

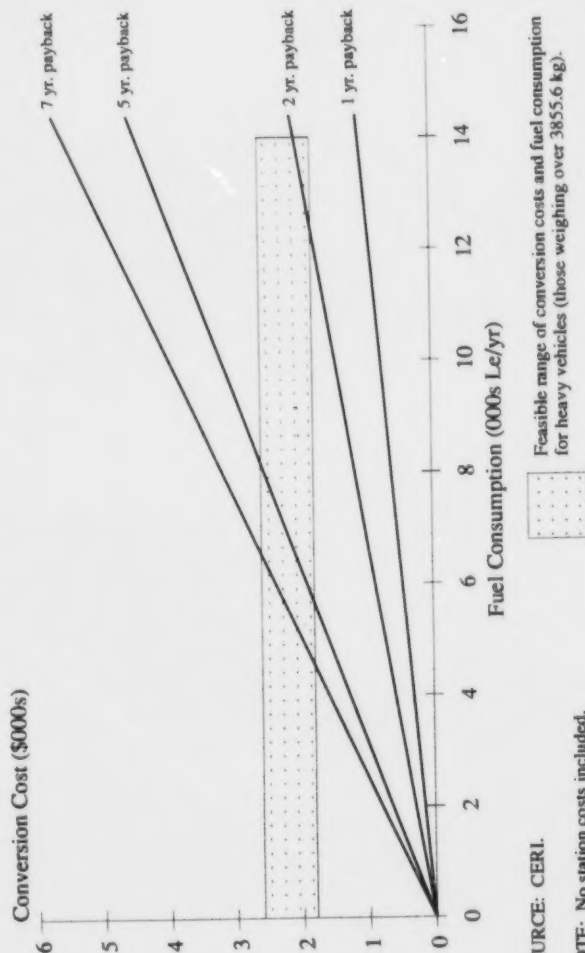


SOURCE: CERL.

NOTE: No station costs included.

- 1 - Typical personal vehicle fuel usage & conversion costs.
- 2 - Typical commercial vehicle fuel usage & conversion costs.
- 3 - Typical high-mileage taxi fuel usage & conversion costs.

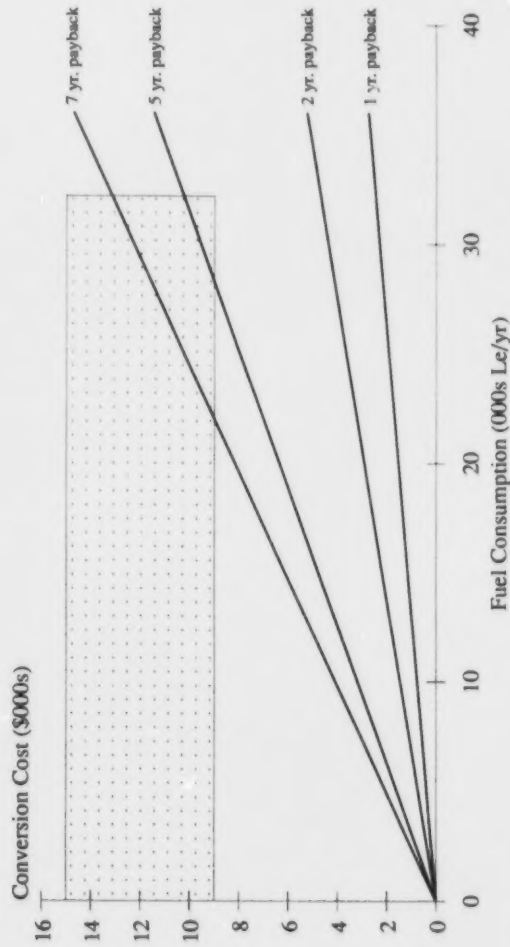
Figure 3.12
Payback Based on Conversion Cost and
Fuel Consumption for Heavy Vehicles



SOURCE: CERL

NOTE: No station costs included.

Figure 3.13
Payback Based on Conversion Cost and
Fuel Consumption for Heavy Vehicles

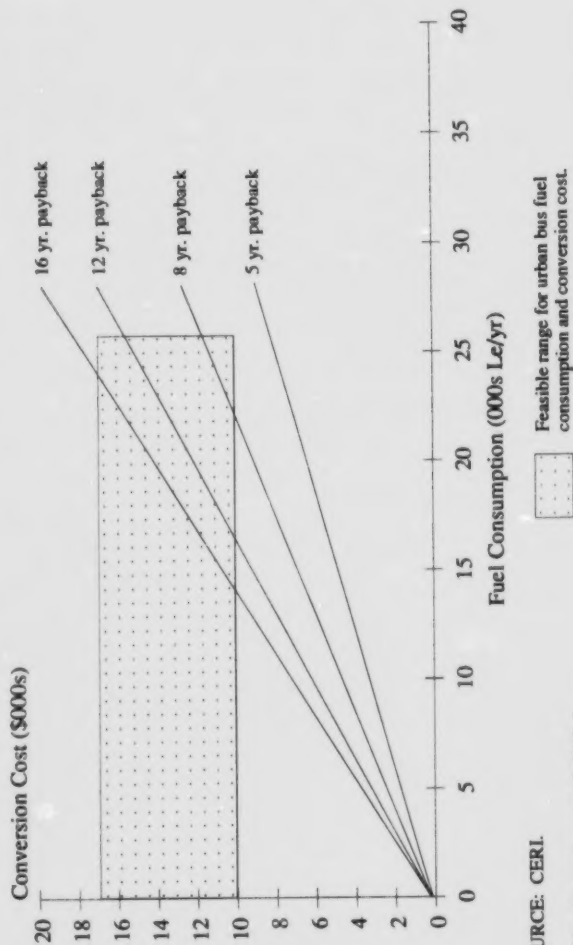


SOURCE: CERL.

NOTE: No station costs included.

Feasible range of conversion cost and fuel consumption for heavy commercial vehicles (47000 kg).

Figure 3.14
Payback Based on Conversion Cost and
Fuel Consumption for Urban Buses



SOURCE: CERL

NOTE: No station costs included.

5000 litre equivalent to gasoline). With a price differential of 16 cents per litre equivalent, these vehicles would save \$763 dollars in fuel costs in the first year (in present value terms) and pay off the \$1400 optimistic costs within two years. Heavy vehicles, weighing over 3855.6 kilograms and travelling 40 000 kilometres a year would also be capable of paying off the \$1800 optimistic costs of conversion within two years. Urban buses travelling 50 000 kilometres a year, on the other hand, would take almost seven years to pay off the \$10,000 optimistic conversion costs.

3.7.4.1 The Price Differential or Market Value of the Fuel in Relation to Gasoline or Diesel

On average, propane in Canada currently benefits from a 16 cent per litre equivalent price differential when compared to regular unleaded gasoline and an 8 cent per litre equivalent price differential when compared to diesel fuel. As with natural gas, this price differential varies between provinces depending on access to supply sources. The greater the price differential, the better are the economics of converting. Obviously, as the price differential between propane and gasoline or diesel fuel increases, the propane consumer will save more on every litre purchased. As the differential decreases, the economic gains of converting to this alternative decline (see Figures F.5 through F.8).

3.7.4.2 The Costs of Conversion

As the OEMs are no longer manufacturing propane vehicles, conversion costs will vary depending on the conversion kit being applied, where the conversion takes place, and how well the conversion kit is installed. There are economies of scale involved when converting large numbers of vehicles rather than single vehicles. The conversion costs being utilized in this analysis are outlined at the beginning of Appendix F. A conversion cost of \$1400, versus one of \$600 (the suggested cost if OEM produced), increases the payout time on light/medium personal vehicles by 35 months or just under three years (see Figure 3.9).

3.7.4.3 Incentives and Subsidies

The elimination of the \$400 federal incentive increased the payback time on retrofitted light/medium vehicles by 21 months and four months for high mileage taxis (see Figures 3.9, F.9 and F.10). Even

more constraining to propane's ability to compete as an alternative fuel, however, was the interpretation which many consumers attached to this policy shift, namely, that the removal of the incentive indicated a loss of government support. Soon after the incentive's elimination, the demand for propane vehicles dropped and the OEMs stopped producing propane powered vehicles. Ultimately, the development and refinement necessary to ensure that conversion parts and equipment maintained comparative development with gasoline vehicles was lost. Cooperative research and development efforts between the Federal and Ontario governments and the Propane Gas Association of Canada (PGAC) are currently trying to rectify this situation.

3.7.4.4 Environmental Incentives and Their Costs and Benefits to the Canadian Citizen

While environmental concerns alone may be sufficient to alter some minor consumer habits, the dramatic decline in the number of propane conversions over the past five years--which has taken place despite propane's status as a clean burning fuel--clearly indicates that financial incentives are necessary if significant modifications in consumption patterns are to be realized. Few consumers appear willing to accept the financial burden of conversion merely on the basis of perceived environmental gains. One possible solution to this problem would be to change the tax structure imposed on vehicle fuels so as to reflect the relevant costs of the emissions each fuel produces upon combustion. This sort of policy action could place alternative fuels on a more equitable footing by allowing the consumer to more accurately incorporate potential environmental costs into his consumption choices.

3.8 Technological Advancements

For the auto-propane industry to expand and gain a larger share of the gasoline and diesel market, further research and development will be necessary in automotive and engineering design to provide optimized carburetion equipment that will meet the low cost, high performance demands of the consumer, the low emissions requirements of the environmentalists, and the conservation and efficiency requirements of the government.

In recognition of the need for further research, PGAC is currently involved in two advanced technology research and development programs for conversion of gasoline engines to propane. One is with Impeco Carburetion of Cerritos, California, where PGAC will be

providing up to twenty vehicles for road testing in 1990. In the other program, in cooperation with ORTECH International, PGAC has provided some of the general data necessary for adapting ORTECH's GFI technology to propane along with an agreement on a vehicle field test program for the system in 1991.

Research underway by ORTECH International (in response to the perceived need for a low cost, clean burning, energy efficient gaseous fuel conversion system) has resulted in the development of the GFI system. This electronic gaseous fuel management system stores propane in a conventional cylinder at pressures up to 128 psi at 26.6°C, then passes it through low pressure tubing to the GFI pressure regulator which drops the fuel to a low, constant pressure of 20 psi. The computer then determines the engine's instantaneous fuel requirements and metered fuel passes through to a nozzle in the air cleaner. The nozzle, in turn, introduces the fuel to the engine's intake air stream. The GFI system also adjusts the ignition system for optimum spark timing (see Figure 3.15).¹¹

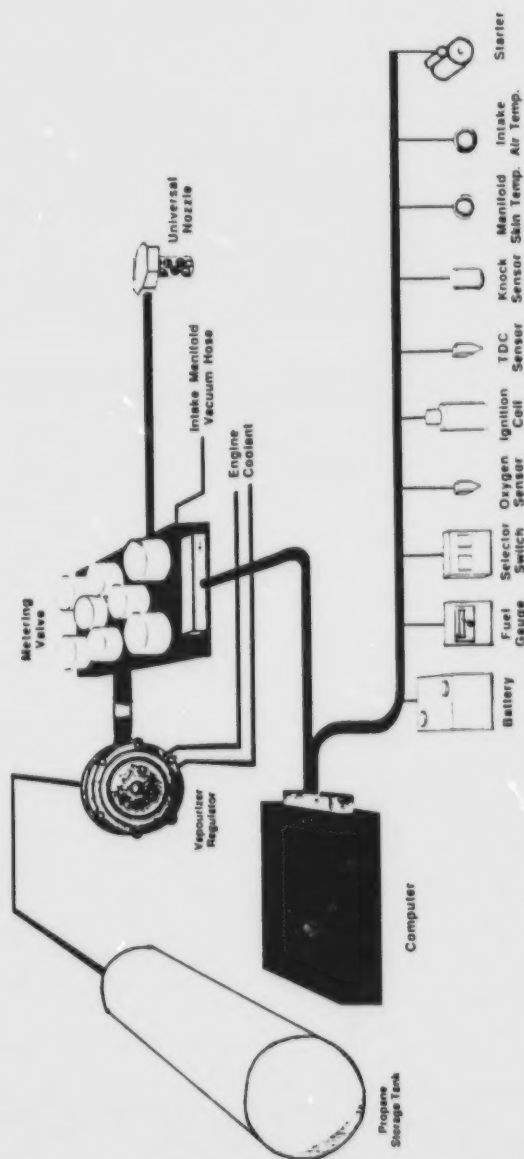
Continued research in propane engine design will result in systems which are compatible with current engine computer control systems, with closed loop capability to optimize performance, fuel economy, and emissions. As well, propane tank streamlining will provide a better fit for aerodynamically designed vehicle exteriors and more efficient use of space.

A major drawback to propane has been that propane fuelled vehicles are not allowed to park indoors in public garages. This is the case by regulation in Alberta and by choice in other provinces depending on whether the vehicle has an automatic stop-fill device. (Of note, as of 1990 all authorized propane conversions must include the installation of such a device.) This safety regulation, a significant deterrent to propane's use in Canada's relatively cold climate, has been enforced to prevent the explosion hazard presented by propane's tendency to accumulate near the ground in the event of a leak. Further research in this area, widespread use of an automatic stop-fill device and further improvements for propane vehicles will help overcome this obstacle and allow for further market penetration.

3.9 Conclusions

Propane, a clean burning, lead-free, high-octane fuel, is the most widely used alternative to gasoline and diesel fuel in Canada. Although domestic supplies are relatively small in comparison to

Figure 3.15
Gaseous Fuel Injection (GFI) System



SOURCE: ORTECH International.

natural gas, current production levels are large enough to ensure adequate supplies to meet domestic demand, as well as to allow about 40 percent of what is produced to be exported. Propane's market niche lies with light/medium commercial vehicles (i.e., taxi-cab companies and delivery services). These vehicles can be converted relatively inexpensively, and their high annual mileage and resulting use of large volumes of fuel provide for the possibility of relatively short payout periods and substantial long-term fuel savings.

There are, however, certain deterrents to greater auto-propane use which must be overcome.

- Expansion of the auto-propane industry is dependent on further research and development in automotive and engineering design, which will meet the performance demands of the consumer, the low emissions expectations of the environmentalists, and the conservation and efficiency requirements of the government.
- Price differentials, which usually favour propane over gasoline and diesel, are affected by the heating market; auto-propane price differentials must stabilize in order to remain competitive in the transportation market.
- Due to health and safety concerns, greater restrictions are placed on sales of auto-propane than on gasoline; further research is required to introduce the possibility of such conveniences as self-serve stations.

Propane's relatively low cost and excellent operating characteristics support its continued utilization in Canadian fleets. There currently exists the refuelling, conversion and service capability, as well as product supply to permit a four-fold increase in conversions in the short term.¹² Expansion of current propane markets, however, will depend on the support of industry, the original equipment manufacturers and the government, as well as technological developments which will allow it to compare favourably in performance, economy and convenience with natural gas, methanol and ethanol.

Footnotes

¹Ford does, however, offer a propane medium-duty truck engine (7.0 litres), as well as a propane prep package (makes internal engine changes providing durability when operated on propane) for 4.9 litre engines for pickups and vans. General Motors also produces parts specifically designed to run with propane fuelled vehicles.

²Canada, Department of Energy, Mines and Resources, *Future Transportation Fuels, Gaseous Fuels, Supply and Services Canada* (Ottawa, Ontario: Supply and Services Canada, 1988), p. 15.

³*Ibid.*, p. 17.

⁴Charles Dempsey, Technical Director, Propane Gas Association.

⁵Ontario Ministry of Transportation and Communications, *Alternative Transportation Fuels, Propane*, produced by Synergistics Consulting Ltd. (Toronto, Ontario: Transportation Technology and Energy Branch, September 1985), p. 12.

⁶*Ibid.*, p. 12.

⁷Discussions with Charles Dempsey, Technical Director of the Propane Gas Association of Canada Inc. on July 13, 1990.

⁸Jeffrey E. Turner and Toros Topaluglu, Ontario Ministry of Transportation and Gary S. Hrynyk, ICG Propane Inc. "Development and Demonstration of a Class 8 Propane-Powered Truck," paper published in the SAE International SP-832 publication entitled *Gaseous Fuels & Other Alternative Fuels* (Warrendale, Pennsylvania: Society of Automotive Engineers, Inc., August 1990), p. 43.

⁹Ontario Ministry of Transportation and Communications, *Alternative Transportation Fuels, Propane*, p. 12.

¹⁰Donald L. Podgurny, ICG Propane, Division of Inter-City Gas Corporation, "Propane Carburetion Market in Canada," paper presented at The World Propane Forum, 1989 Conference and Exhibition, Monte Carlo, Monaco, October 11-13, 1989, Table 3.

¹¹Steve Carter, ORTECH International, "Presentation at the 1990 Windsor Workshop on Alternative Fuels," in Toronto, Ontario, Sponsored by Energy, Mines and Resources Canada, U.S. Department of Energy and Ontario Ministry of Energy, June 11-14, 1990, p. 2.

¹²Propane Gas Association of Canada Inc., "Presentation at the General Motors of Canada Alternative Fuels Seminar," July 5, 1990, p. 7.

Chapter 4

METHANOL

4.1 Introduction

Canada is one of the largest producers of methanol in the world, with 85 percent of its production currently being exported to the United States, Japan and Europe (see Figure 4.1). Canadian producers, therefore, compete in what is very much a world market, a market which has been characterized by surplus capacity and volatile prices.

Methanol's principal uses in Canada have historically been as a solvent and chemical feedstock. More recently, with the growing concern for energy security and the demand for clean burning fuels, methanol has become one of the front runners in the alternative fuels race. As such, it is being considered as a petroleum substitute in transportation markets as a "neat" and/or "near-neat" fuel, and is being tested in flexible fuel passenger cars and urban buses. Neat methanol is defined as 100 percent methanol and near-neat is defined as a methanol blend containing a small fraction of hydrocarbons. M85, containing 85 percent methanol, is the most common methanol blend.

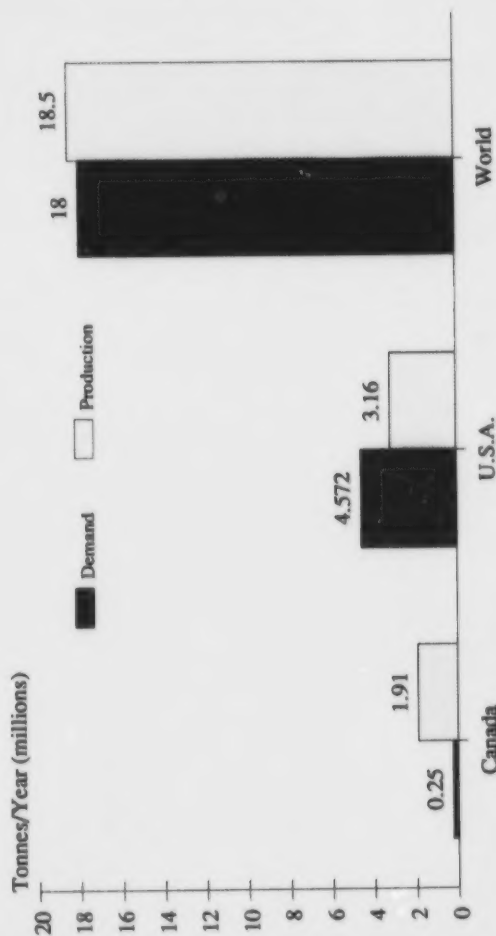
The internal combustion engine and the fuels currently being used in these engines have generated a major portion of the anthropogenic¹ pollution present in the atmosphere, and it is hoped by many that increased use of methanol instead of gasoline and diesel may provide a partial solution to these pollution problems. The recent demand growth for methanol in the transportation industry, however, has come from the manufacture of methyl tertiary butyl ether (MTBE), an oxygenate which is used as a substitute for octane enhancing lead which was banned from Canadian gasoline as of December 1990.

4.2 Technical Assessment

4.2.1 Production

Methanol can be produced from natural gas, coal and biomass. However, abundant supplies of relatively cheap natural gas have made it the feedstock of choice in Canada to date. Using coal or biomass as feedstock would require a more complex conversion process than the one used in the production of methanol from natural gas, and thus would entail higher production costs. Advanced technology for

Figure 4.1
World Methanol Production/Demand
1988



SOURCE: COFA: Presentation to Canadian Gas Association, May 18, 1988.
NOTE: Canadian stats updated to 1989.

utilizing coal in plants designed for the co-generation of both methanol and electricity may prove viable in the long-term with production costs as low as 20 to 30 cents (US) per US gallon and electricity at 2 cents (US) per kilowatt hour.²

4.2.1.1 Methanol from Natural Gas

Methanol currently produced in Canada is derived from methane, the primary component of natural gas, using a two-stage process involving the following basic steps (see Figure 4.2):

- Sulphur from the natural gas and impurities from the water feed are removed.
- Gas and steam are fed into a reformer where the natural gas and steam are catalytically reformed into synthesis gas (syngas).
- The syngas is dried, cooled and compressed, then fed to a converter.
- In the converter, these gases are reacted under pressure in the presence of a catalyst to form methanol and water.
- Methanol is removed from this solution via distillation.

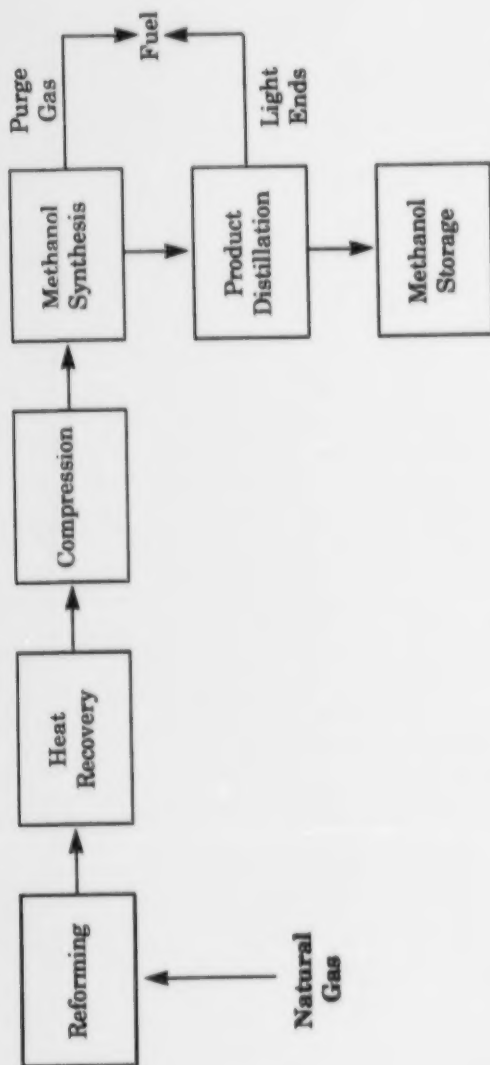
4.2.1.2 Methanol from Coal

Canada's coal reserves are immense, containing 2.3 times the combined energy in all of Canada's other non-renewable energy sources.³ Coal liquefaction may prove viable in the future should the demand for methanol in the transportation industry attain levels which drive the methanol fuel price high enough to support the production of methanol from coal. This is not likely in the near or medium term.

Conversion technologies for producing methanol from coal involve a number of phases:

- **Preparation:** The coal is prepared by grinding it to a specific size and adding water to form a slurry, allowing it to be pumped into a gasifier.
- **Gasification:** High pressure is applied to the slurry to allow for catalytic conversion into a gas. Much of the waste heat that is required in this phase is recovered as steam. The particulates of ash in the syngas are removed via scrubbing.

Figure 4.2
Natural Gas to Methanol



SOURCE: DM International, Production of Methanol from a Combination of Wood and Natural Gas Feedstocks, presented at the First International Conference on Fuel Methanol (Houston, Texas: October 1982).

- * **Purification:** CO_2 and H_2S , unwanted products of the reactions in the gasification process, are removed by scrubbing with an appropriate alkaline mixture, leaving the syngas as a mixture of CO and hydrogen (H_2).

Coal-to-methanol conversion plants are based upon the process whereby syngas is passed over catalysts at high temperature and pressure to accelerate methanol formation (see Figure 4.3).

4.2.1.3 Methanol from Biomass

Methanol, historically referred to as wood alcohol, can also be produced from renewable feedstocks such as wood or agricultural and municipal wastes, which can also be used to produce synthesis gas. This conversion procedure involves shredding biomass, then heating it at high temperatures in the presence of a limited quantity of oxygen. Figure 4.4 illustrates the sequence of processing steps required to convert biomass to methanol.

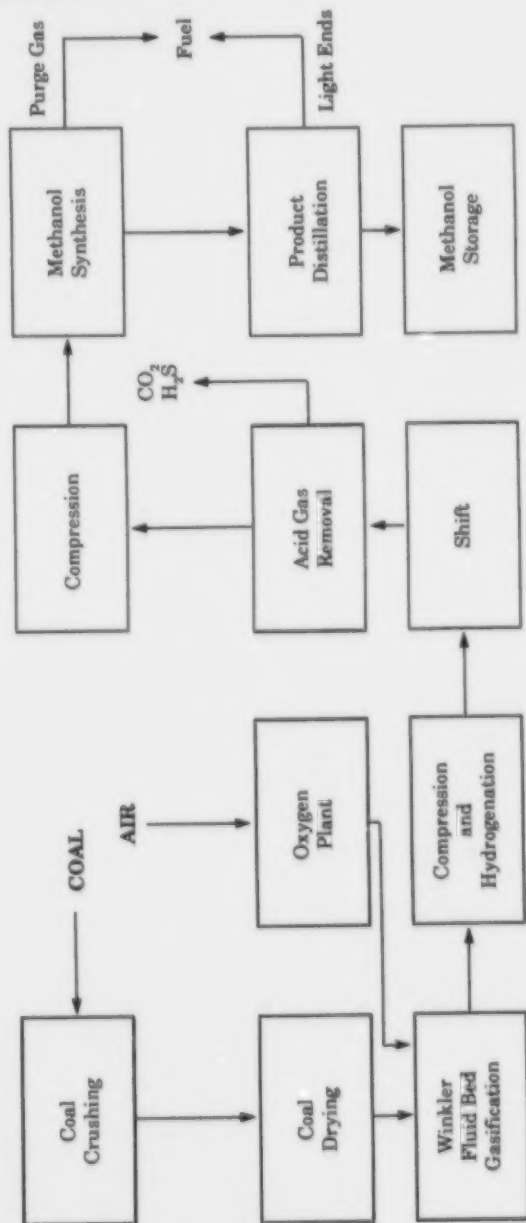
4.2.1.4 Methanol from Combined Feedstocks

During the oxygen/steam-gasification process, various feedstocks give hydrogen/carbon monoxide ratios lower than those desired. However, steam reforming of natural gas actually yields a higher ratio. Gas consumption adjustment may be attained by rejection or removal of the CO_2 , or addition of hydrogen from an alternate source by combining natural gas and heavy oil or solid feedstocks. As Canada has abundant feedstock resources, a number of hydrogen donor processes have been researched, one of which is hydrogen addition through electrolysis, along with the simultaneous production of the oxygen required for the gasification of the solid feedstock (peat or wood). Combinations of natural gas and peat feedstocks with and without CO_2 removal have also been explored. Optimal production may result from a combination of these processes in an integrated plant (see Figure 4.5). In spite of improved efficiency and lower investment costs, however, methanol production costs from these new processes are higher than those associated with the use of natural gas as a feedstock.⁴

4.2.2 Composition and Characteristics

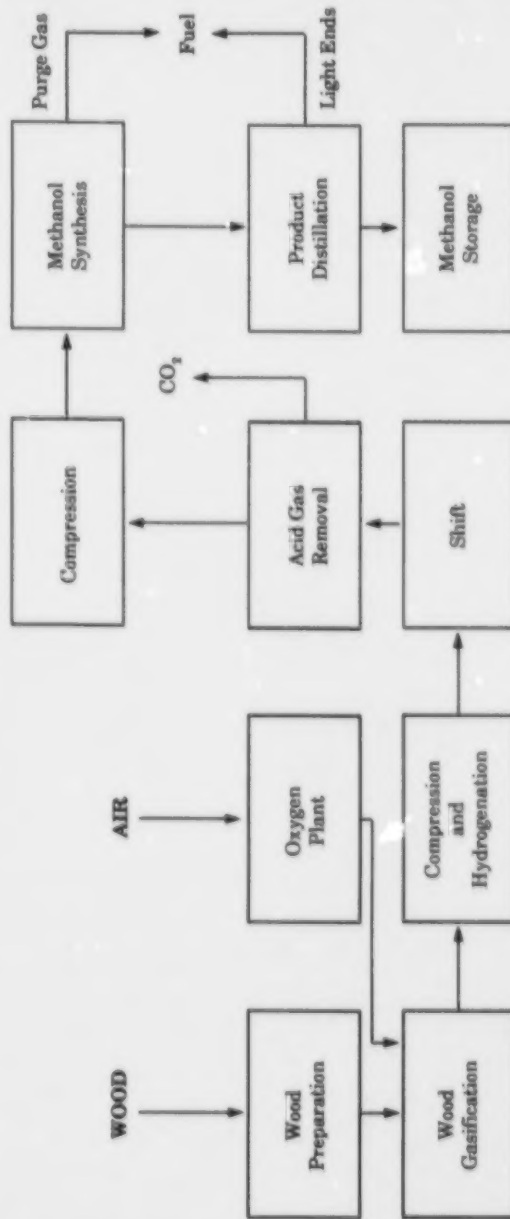
Methanol is a clear, colourless, toxic liquid. This simple organic alcohol is miscible with water, ether and other alcohols.

Figure 4.3
Coal to Methanol



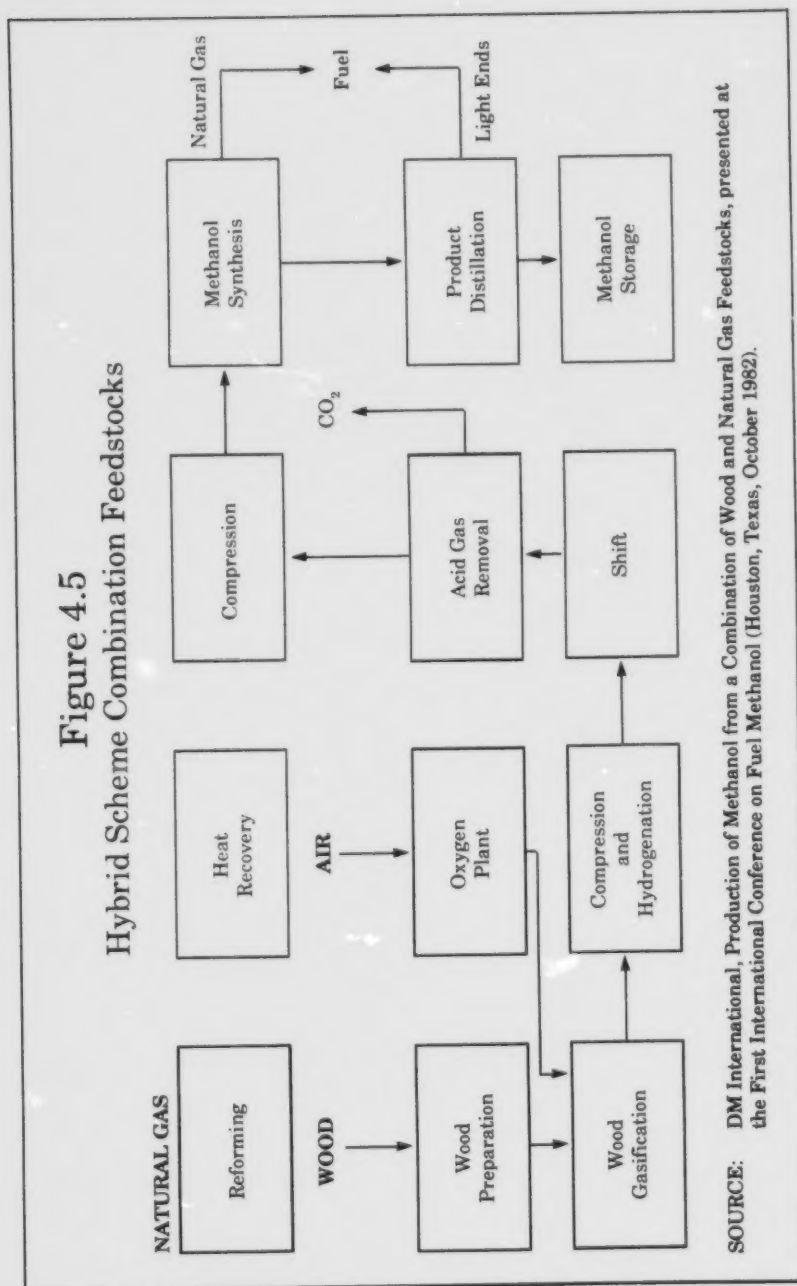
SOURCE: DM International, Production of Methanol from a Combination of Wood and Natural Gas Feedstocks, presented at the First International Conference on Fuel Methanol (Houston, Texas, October 1982).

Figure 4.4
Wood to Methanol



SOURCE: DM International, Production of Methanol from a Combination of Wood and Natural Gas Feedstocks, presented at the First International Conference on Fuel Methanol (Houston, Texas, October 1982).

Figure 4.5
Hybrid Scheme Combination Feedstocks



SOURCE: DM International, Production of Methanol from a Combination of Wood and Natural Gas Feedstocks, presented at the First International Conference on Fuel Methanol (Houston, Texas, October 1982).

Methanol is produced from syngas which consists of carbon monoxide, carbon dioxide and hydrogen.

The physical characteristics of methanol are highlighted in Table A.1. The chemical properties of this fuel impose metal and elastomer requirements on methanol fuelling systems which differ from those of gasoline fuelling systems.

Unlike gasoline, which exhibits relatively narrow flammability limits, methanol stored in closed containers is theoretically explosive at temperatures from between 10 to 40°C. However, methanol's excellent conductive properties reduce the probability of static electricity igniting the vapour which forms above the liquid surface.

Further reduction of the risk involved in storing methanol in vehicle tanks can easily be achieved through the installation of flame arrestors on vents, or the addition of light hydrocarbons to the fuel mix (as in M85 blends). In the case of spillage, it can be concluded that methanol is less hazardous than gasoline, but more hazardous than diesel fuel, if the fuels' relative flashpoints are taken into account.⁵ It should be noted that alcohol-resistant foams are available for fire-fighting purposes.

4.2.3 Uses as a Petroleum Substitute

Methanol, recognized as an efficient, clean burning, high octane fuel (with octane numbers ranging from 105 for M85 to 110 for M100),⁶ is currently gaining interest from the transportation sector for its potential use as:

- a raw material in the production of MTBE;
- a neat or near-neat alternate fuel for gasoline in dedicated or flexible fuel vehicles; and
- a substitute for diesel fuel, particularly in buses.

4.2.3.1 Methyl Tertiary Butyl Ether

Currently, methanol makes its major contribution to motor fuel supplies as a component in the production of MTBE, a high octane gasoline additive.

The typical octane blending properties of MTBE in higher octane gasoline are:

<u>Octanes</u>	<u>Blending Properties</u>
Research (RON)	117
Motor (MON)	99
(R+M)/2	108
Front End (RON 100°C)	135

With lead phasedown, MTBE's 108 ((R+M)/2)) blending octane makes it a potential octane additive that can be blended inside the refinery with little, if any, distribution limitations on the resulting gasoline product (see Table 4.1). The octane bonus from MTBE is dependent on the MTBE concentration. Gasoline containing 10 percent MTBE will act like a hydrocarbon-only gasoline that is one octane number higher. In Canada, MTBE is allowed as a blending component in unleaded gasoline in concentrations up to 11 percent.

TABLE 4.1
PRICING MTBE BASED ON OCTANE VALUE
(Cdn cents per litre)

	10 Percent Concentration ^a
Unleaded gasoline price ^b	23.00
Value of blend based on octane efficiency	28.55
Value of blend based on price ^c	24.00

SOURCE: Canadian Energy Research Institute.

^aAt a 10 percent concentration, MTBE has an octane value 24 percent higher than unleaded gasoline.

^bRack price.

^cThe spot price of MTBE on October 3, 1988 was 95 cents per gallon (US/US) or 33 cents per litre (Cdn/Cdn) [(0.9 X 23) + (0.1 X 33)].

Table 4.1 indicates the value of a 10 percent concentration of MTBE when added to gasoline. As MTBE can be produced from normal butane or a butane mix for approximately 22 to 23 cents per litre, it is also an economically viable octane-enhancer.⁷

With both a low boiling point and a lower-than-gasoline Reid vapour pressure (RVP), MTBE's unique volatility relationship has made it known not only as an octane-enhancer but as a "driveability

index improver".⁸ This additive does not foul or plug the fuel injectors used in late model cars, and can actually reduce this problem in many cases.⁹

Environmentally, MTBE as an oxygenate reduces the carbon monoxide and unburned hydrocarbon emissions in a car's exhaust through fuel enleanment. In addition to these exhaust emission benefits, MTBE's low oxidation rate suggests that gasoline blended with MTBE will likely contribute to a reduction of smog build-up.

4.2.3.2 Methanol as a "Neat" Alternative for Gasoline in Flexible Fuel Vehicles

The past ten years have seen the development of cleaner burning, more efficient engines and substantial reductions in the levels of noxious emissions. There has also been a steady increase in the number of vehicles on the road. With this expansion has come a growing concern as to how it will be possible to continue to reduce the amounts of pollutants being emitted into the atmosphere each year. One of the solutions being examined is the use of methanol in flexible fuel or dedicated vehicles.

Heavy-duty vehicles represent only four percent of all of Canada's highway vehicles and yet this sector has been identified as a major contributor of atmospheric pollutants, particularly in urban areas (see Table A.2).¹⁰ The quality of diesel fuels is decreasing as the sulphur and aromatic content of these fuels increases. Diesel particulates, which carry carcinogenic compounds to human lungs and reduce atmospheric visibility, result from incomplete combustion of the fuel. Engines designed to operate on methanol, which itself would burn free of particulates, are being considered as near-term potential substitutes for diesel engines. These engines provide an attractive option for meeting the new heavy-duty vehicle emissions standards proposed for 1991 and 1994 (see Table B.8), providing production of the methanol engines does not prove to be too costly.

4.3 Performance and Compatibility with Current Vehicles and the Fuel Distribution System

4.3.1 Compatibility with Current Vehicles

Methanol engine technology is developing for both light-duty and heavy-duty engines. Long recognized as a high octane, high

performance fuel used in the Indianapolis 500 race cars, methanol can be used in both spark-ignition and diesel engines.

Methanol has only half the energy content of gasoline but has 10 to 20 percent better thermal efficiency. The result is improved vehicle performance, with as much as 5 to 20 percent more specific power.¹¹ Methanol's lower flame temperature and faster flame speed release the heat of combustion more efficiently, yielding a reduction of heat transfer losses. However, methanol's increased efficiency does not compensate entirely for its lower energy density, so that drivers using methanol in vehicles fitted with standard-size gasoline tanks would require about 1.7 times more fuel for an equivalent driving range.

Spark-ignition engines, whether carbureted or fuel injected, are generally used for light-duty applications such as passenger cars. Use of methanol in these engines requires no major structural changes. The modifications that are necessary involve adjustments to the fuel system to assure the correct air/fuel ratio, possible alterations to the spark timing, the addition of a cold start system, and reformulated motor oils to provide adequate corrosion protection and lubrication. The cold startability problem is a result of methanol's low volatility coupled with its high heat of vapourization. However, the cold startability of methanol improves greatly when a small amount of startability improver such as gasoline is mixed in methanol,¹² a benefit provided by M85.

Vapour lock can be a problem in very hot climates, as the boiling point of methanol is much lower than that of gasoline. If temperatures are in the 39°C range and the vehicle has been warmed, driven, turned off and left to sit, enough methanol may vapourize to "lock" the fuel lines. Ford solved this problem with an additional low-pressure electric fuel pump and a larger fuel filter.¹³

Power and performance testing performed on retrofitted or purpose-built cars show both superior performance and reduced harmful emissions in comparison with gasoline fuelled cars. Data indicates that engines designed to run on methanol tend to be more powerful than engines designed to run on gasoline. Ford tested a 1.6 litre methanol engine which showed 17 percent more brake horsepower at wide-open throttle than a gasoline model. Also, when operated on methanol, the Ford Flexible Fuel Vehicle is almost one second faster in accelerating from 0 to 60 miles per hour than when powered by gasoline. The Ford Crown Victoria, converted to run on an M85 gasoline

blend, was 3 percent faster in accelerating from 0 to 65 miles per hour than the same gasoline powered vehicle.¹⁴

Development of the necessary infrastructure for fuelling will provide an opportunity for the development of engines designed to operate on M100. Neat methanol would yield a number of advantages over gasoline, including, higher compression ratios, higher heat of vapourization providing cooling during the compression stroke, and higher flame speeds combined with broad flammability limits, permitting more ideal timing and leaner mixtures for increased thermal efficiency.¹⁵

However, M85 may remain preferable to M100 because of the flame visibility concern and methanol's flammability limits which make the vapour above the liquid in the tank with alcohol fuels more ignitable at normal ambient temperatures than would be the case with gasoline. Adding a small amount of gasoline to the alcohol, as is the case with M85, creates a yellow flame in the case of fire and shifts the flammability limits of the blend to temperatures more like those of gasoline.¹⁶

4.3.2 Distribution

Methanol, like other liquid transportation fuels, can be moved by pipeline, truck, rail and ocean tanker or barge. Transmountain Pipelines has successfully transported methanol through their pipeline. Even though the methanol was "batched" through a crude oil pipeline, motor grade methanol was attained at the receiving end of the pipeline. If continuous pipeline transportation of methanol were to occur, however, present pipeline systems would have to be upgraded. Incremental costs may be necessary for dewatering and corrosion prevention.¹⁷ Transportation of pure methanol would also require the use of rubber "spheres" to physically separate the products being transported.

Alcohol, unlike gasoline, is soluble in water. Shipping and using alcohol as a distinct product should, in fact, not pose a problem as alcohol actually burns more efficiently with water in it.¹⁸ However, once blended with gasoline, should the blended product come in contact with water, the alcohol would absorb the water and separate from the gasoline, resulting in two liquid phases.

The degree of separation depends not only on the quantity of water present but the proportion of alcohol present, the composition of the gasoline, and the temperature of the air and liquids. Although

phase separation occurs when even small quantities of water are present, the responsiveness of the alcohol/gasoline blends to water decreases substantially at higher temperatures and as the proportion of alcohol increases beyond 10 percent.¹⁹

As both tankers and barges have been used to transport chemical-grade methanol, shipping fuel-grade methanol should be feasible. Water penetration can occur, but this problem may be avoided with routine cleaning and checking of the tanks, pipes and valves of ships used to transport more than one type of cargo, or through the use of dedicated vessels designed to maintain product integrity.

Both tank trucks and rail tankers can be used to transport methanol. If the transport vehicle has been used to transport a product other than alcohol, standard industry practice requires that the containers first be cleaned and purged to prevent contamination.

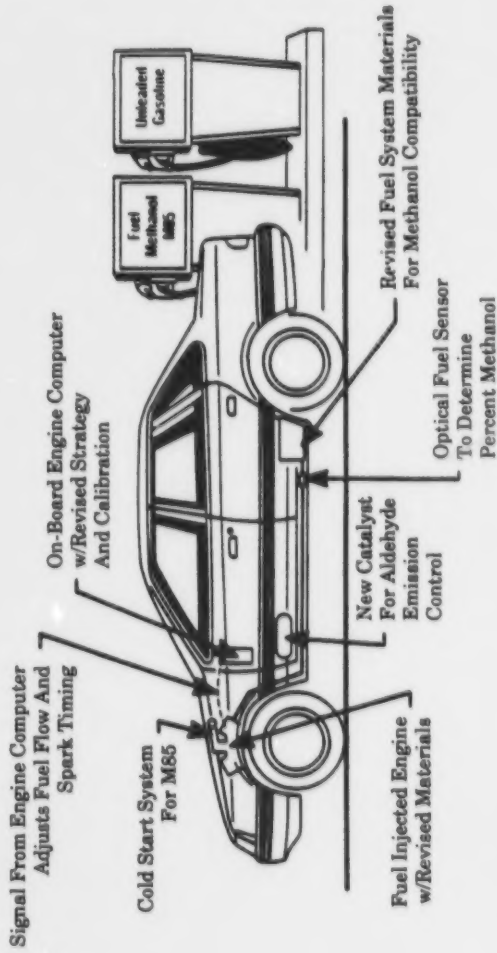
As methanol contains approximately half the energy of gasoline or diesel fuel, the large-scale production and use of fuel methanol would require storage facilities with almost twice the capacity of those required for gasoline or diesel fuel.

Although methanol has deleterious effects on various materials found in current distribution systems, the long history of methanol use in the chemical industry has resulted in practical solutions to any problems which may be encountered when transporting this alcohol. In other words, sufficient technical experience has been accumulated to overcome any of the technical problems which may be encountered when transporting blended fuels or fuel alcohols.

4.4 Vehicle Options

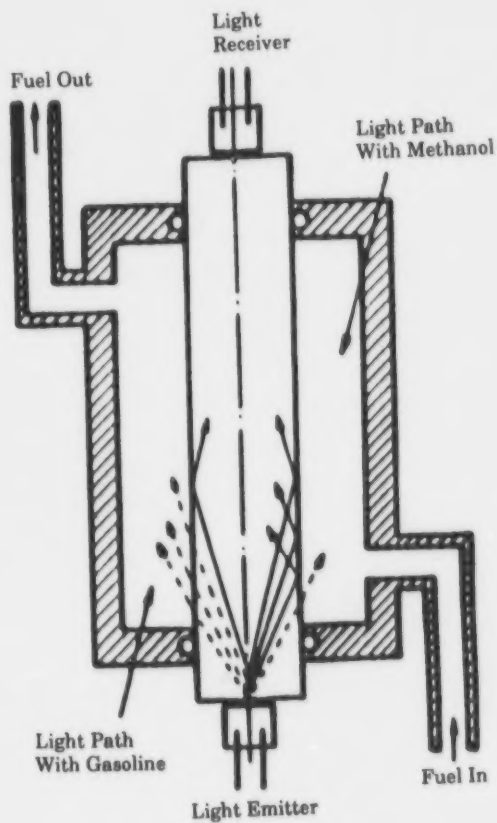
Major vehicle and engine manufacturers worldwide are experimenting with methanol vehicles. Although most of these are dedicated vehicles designed to operate on pure methanol (M100), the three major United States auto manufacturers are experimenting with multi-fuel vehicles designed to automatically convert from operating on 100 percent unleaded gasoline to methanol/gasoline blends of up to 85 percent methanol. One example, Ford's FFV, has an optical fuel sensor which measures the percentage of methanol in the fuel mixture and adjusts the fuel injection system and spark timing as required to ensure proper blending (see Figures 4.6 and 4.7).

Figure 4.6
Ford Flexible Fuel Vehicle (FFV)
Major Unique Components



SOURCE: Ford Motor Company.

Figure 4.7
Optical Sensor Schematic



SOURCE: Ford Motor Company.

4.5 Environmental Impacts

Environmental considerations and public concern about carbon monoxide levels, ground level ozone formation and the greenhouse effect have reinforced the movement towards alternative fuels. Canadians are researching the potential of methanol, both for light/medium vehicles and as a replacement for use in diesel powered urban buses, since methanol emits lower levels of reactive hydrocarbons and burns without producing soot.

The State of California is investigating the use of alternative transportation fuels and low-emission motor vehicles which are cleaner-burning than petroleum based fuels and will reduce the current air pollution problems (i.e., M85 in flexible fuel vehicles). Twelve air basins in this state did not meet the Clean Air Standard for ozone by the December 31, 1987, federal deadline, including the South Coast Air Basin.²⁰ A portion of the methanol requirements projected for California will come from Canada, as will some of the flexible fuel vehicles.

In October 1990, General Motors of Canada announced that it will produce 2300 specially designed Chevrolet Lumina's that can operate on M85. Most of these cars, which will be built at GM's Oshawa plant, are destined for California. One hundred and ten cars however, will be test-driven in government fleets in Ottawa, Toronto, Edmonton and Vancouver in a federally assisted program designed to determine the feasibility of methanol as a cleaner burning alternative to gasoline.²¹

4.5.1 Production Impacts

The least environmentally damaging methanol production process is undoubtedly the steam reforming of natural gas. Not only are the extraction, refining and distribution of natural gas fundamentally nonpolluting, but the conversion process itself is also relatively simple, with few by-products.

Greenhouse gases are produced from the combustion of all carbon-containing fuels, and methanol is no exception. However, if methanol were to be produced from flared or vented natural gas, a relatively large global warming benefit could result, as this natural gas is, at present, simply being dumped into the atmosphere, where it contributes to the greenhouse effect without ever having been utilized to produce useful energy. An estimated 2.7 billion cubic metres of natural gas was flared in Canada in 1987.²² If the natural gas

feedstock utilized was not originally destined to be flared or vented, methanol production would result in equal or slightly lower greenhouse gas emissions, relative to gasoline produced from crude oil.²³

Converting coal to methanol is likely the method of methanol production with the most deleterious consequences for the atmosphere. In fact, producing methanol from coal could almost double greenhouse gas emissions,²⁴ while also contributing to emissions of SO_x and almost all other regulated pollutants. In addition, toxic metals and carcinogenic polycyclic hydrocarbons are potential by-products from this methanol production option.²⁵ Future developments in clean coal technology, by providing for better recovery of methane at the coal mine and carbon dioxide at the production plant, could possibly reduce the global warming impact of this process to a level comparable to, or even less than, the production of gasoline from crude oil. However, further research and development will be required in this area.

The use of wood as a feedstock in the methanol production process results in lower SO_x emissions than does the use of coal, but NO_x and particulate emission levels are similar in both procedures. A large global warming contribution could result in the event that a significant level of biomass was used as a methanol feedstock as the CO_2 produced in combustion can be reabsorbed into new biomass feedstock (see Tables A.6 and A.7).

Methanol, produced in Alberta from other than flared or vented gas, is likely to be derived from sour natural gas containing approximately 20 percent sulphur. As noted in Section 2.3.1, before sour gas can be pipelined to a methanol plant, the gas must be sweetened so that it does not exceed the sulphur content limits allowed by pipeline regulations. The emissions produced during this sweetening process should certainly be included in any estimate of methanol production emissions, since feedstock preparation is just as integral a part of methanol production as is the conversion process itself. The emissions released from sweetening the natural gas required to produce a litre of methanol are approximately 36 percent lower than those resulting from the production of a cubic metre of natural gas, since although 0.622 cubic metres of natural gas is equivalent to one litre of methanol, a litre of methanol requires approximately 0.641 cubic metres of natural gas for its production because the process is only 97 percent efficient.²⁶

Various other pollutants are emitted in the methanol production process. These emissions are summarized in Table 4.2. Table 4.3 summarizes the total emissions generated in the preparation of methanol, under the assumption that methanol's density is 0.794 kilograms per litre.

4.5.2 Vehicular Emissions

Methanol's chemical composition differs from gasoline. The result is different evaporative and exhaust emissions from neat or near-neat methanol which themselves contain high concentrations of methanol. As well, the unburned exhaust gases consist of higher levels of formaldehyde, with little or no benzene, other aromatics, polyaromatics, or olefins.²⁷

Exposure to formaldehyde, which is considered to be carcinogenic, is an important air toxic concern. Burning methanol produces more formaldehyde than burning gasoline; therefore, catalytic converters would be needed on methanol vehicles to reduce formaldehyde levels to those produced by gasoline (see Tables 4.4 and 4.5). Neat methanol use may not, however, lead in the long-term to increased ambient formaldehyde levels and ultimately cancer cases. Most of the ambient formaldehyde is formed indirectly in the atmosphere through photochemical reactions involving reactive hydrocarbons. This suggests that neat methanol engines, with their lower hydrocarbon emissions, would actually decrease indirect formaldehyde formation in comparison to gasoline vehicles. The decreased amount of formaldehyde formed indirectly may well offset any increase in direct formaldehyde emissions.²⁸

Methanol and formaldehyde are both toxic at elevated concentrations. Both the EPA and the Royal Society of Canada have concluded, however, that methanol and/or formaldehyde levels high enough to be of concern would likely only occur under extreme conditions, such as when a vehicle is left idling for extended periods of time in a private garage. Gasoline would also produce dangerous levels of emissions under these circumstances. Both the effects to health of direct formaldehyde emissions versus indirect formaldehyde formation, as well as the public health concerns regarding exposure to increased levels of methanol, will continue to be examined.

The major environmental benefits of increased methanol use are lower levels of reactive hydrocarbon emissions, resulting in reduced ozone formation. The VOCs emitted from methanol vehicles consist mainly of unburned methanol, which has approximately

TABLE 4.2

CONTINUOUS METHANOL PLANT EMISSIONS
(grams per metric tonne of methanol produced)

	Airborne Emissions		
	CO ₂	NO _x	CO
Package Boiler Flue Gases	9 953	19	10
Reformer Flue Gases	394 572	1 004	502
Flare Pilot Flue Gas	3 764	7	34
Non Condensable - Purge Gas	5 244	0	0
Degassifier Exhaust	195	0	0
Condensate Exhaust	1 295	0	0
Deaerator Exhaust	31	0	0
Absorber Exhaust	15 679	0	0
Total	430 733	1 030	860

SOURCE: Energy, Mines and Resources Canada, *Cost-Effectiveness of Alternative Transportation Fuels In Urban Buses* (Ottawa, Ontario: CANMET, November 1989), p. 60.

TABLE 4.3

TOTAL EMISSIONS FROM METHANOL PREPARATION
(grams of emissions per litre of methanol produced)

	HC	NO _x	CO	Part	CO ₂	SO _x
N.G. Prep	0.0092	0.1506	0.0622	N/A	66.7781	0.107
Methanol Production	neg	0.82	0.68	neg	342	neg

SOURCE: Energy, Mines and Resources Canada, *Cost-Effectiveness of Alternative Transportation Fuels In Urban Buses* (Ottawa, Ontario: CANMET, November 1989), pp. 60 and 61.

TABLE 4.4

GENERAL MOTOR CORPORATION - VARIABLE FUEL
1988 CORSICA WITH PRODUCTION CATALYST
4,700 MILE DATA '75 FTP EMISSIONS
(grams/mile)

Fuel	OMHCE ^a	CO	NO _x	HCOH	HWY NO _x
MO	0.28	2.3	0.2	0.004	0.15
M25	0.28	2.7	0.2	0.006	0.10
M50	0.22	2.0	0.2	0.012	0.20
M85	0.26	2.4	0.2	0.025	0.15
Standards					
Federal	0.41	3.4	1.0	---	---
California	0.41	7.0	0.4	0.015	0.53

SOURCE: Ament, F., *Tailpipe Emissions from GM Variable-Fuel Corsicas* (Warren, Michigan: General Motors Corporation).

^aReported per EPA procedure.

SYNOPSIS: Using the gasoline production emission control hardware, the Variable-Fuel Corsica meets the current Federal and California tailpipe emissions standards at low mileage. The level of Organic Material HC Equivalent, CO and NO_x emissions remains relatively constant with fuel blends ranging from 100 percent gasoline, up to 85 percent methanol.

However, the formaldehyde emissions increase from 4 mg/mile with gasoline, to 25 mg/mile with M85. Most of the tailpipe formaldehyde emissions occur during the cold portion of the Federal Test Procedure, before the catalytic converter is fully active. For reference, the formaldehyde emissions jump to 35 mg/mile with M100.

Although faster converter warm-up reduces formaldehyde emissions, compliance with the 15 mg/mile standard at 50,000 miles would still be questionable.

TABLE 4.5

OAK RIDGE NATIONAL LABORATORY
EMISSIONS TEST RESULTS CALCULATED
BY ORNL PROTOCOL

Abstract

Argonne National Laboratory has completed two full years of operation of 19 vehicles in the Federal Methanol Fleet Project; ten of the vehicles are fuelled with methanol. Over one-half million miles have been accumulated on the fleet vehicles so far, and comparisons of efficiency continue to show nearly equal performance between the methanol and gasoline vehicles. Emissions tests of some of the vehicles during the second year revealed degradations of emissions control systems for both the methanol and gasoline vehicles types, although emissions were still within legal limits. Methanol vehicles continued to require more maintenance, and the maintenance labour intensity (hours per 1000 miles) increased for all the vehicle types being monitored. Accumulation of metals in the lubricating oil of the methanol vehicles continued to be elevated compared to that of the gasoline vehicles although not at alarming levels. Drivers indicated less satisfaction with vehicles in the test during the second year, both for methanol as well as gasoline vehicles.

Vehicle	Mileage (miles)	FTP Results (gm/mile)			
		OMHCE ^a	CO	NO _x	MeOH ^a
<u>Methanol Chevrolets</u>					
ME 562	381	0.16	0.74	0.51	0.40
	7,600	0.72	8.27	0.67	1.28
ME 568	288	0.25	1.39	0.43	0.55
	8,700	0.44	6.36	0.85	0.82
<u>Methanol Fords</u>					
ME 572	793	0.18	0.76	0.62	0.54
	32,800	0.70	2.23	0.79	1.27
ME 574	418	0.23	1.44	0.63	0.56
	26,900	0.65	3.16	0.71	1.17

SOURCE: R.N. McGill, S.L. Hillis, B.H. West, and J.W. Hodgson, *Results from the Second Year of Operation of the Federal Methanol Fleet at Argonne National Laboratory* (Oak Ridge, Tennessee: Oak Ridge National Laboratory, August 1989).

^aThe unburned fuel emissions (MeOH, NOHC, and aldehydes) are reported as the organic hydrocarbon equivalent, OMHCE.

one-fifth the reactivity of the average gasoline vehicle's hydrocarbon emissions. Recent studies undertaken in the United States by the EPA indicate that methanol flexible fuel vehicles (FFVs), on a reactivity-equivalent basis, will emit at least 30 percent less VOCs than typical future vehicles of corresponding ages, while dedicated methanol (M100) vehicles are projected to emit 80 percent less VOCs than future gasoline vehicles of equal age (see Table 4.6).²⁹

Methanol combustion tends to produce fewer nitrogen oxides than the combustion of gasoline. This is largely due to the greater internal cooling effect from the alcohol's high heat of evaporation and lower flame temperature.³⁰

Of interest is the EPA finding that at low temperatures, both dedicated vehicles and FFVs may exhibit poorer CO performance than gasoline vehicles in the absence of low temperature standards for either of these vehicle types.³¹

While it may be possible to configure engines for reduced CO and hydrocarbons, with M85 the reduction is usually at the expense of increased NO_x levels. Conversely, adjusting the engines to reduce NO_x is at the expense of higher CO. This dilemma exists because CO and hydrocarbons are oxidized best in excess air in the engine and catalytic converter, whereas NO_x is reduced most effectively by a catalyst in oxygen-poor conditions.³²

The proposed Canadian medium- and heavy-duty diesel standards, as well as those defined by the EPA, have as their major focus the severe reduction of particulate emissions. Methanol, which has demonstrated potential advantages over petroleum fuels in terms of emissions of reactive hydrocarbons, nitrogen oxide, smoke and particulates, is being considered as a potential fuel in Canadian urban buses (see Table 4.7). However, when compared to newer advanced technology diesel engines, total emissions when burning M100 increased due to methanol's higher CO emissions relative to diesel. It must be noted, however, that these CO emissions are still within regulated emission standards.³³

TABLE 4.6
PROJECTED IN-USE ORGANIC EMISSIONS FOR
GASOLINE AND METHANOL VEHICLES
(grams per mile)

Type of Emission	Gasoline Vehicles, Current Standards (9.0 psi)			Gasoline Vehicles Under Standards Proposed by President Bush (9.0 psi)			Interim Technology FFV's on M85 in 1995-1999			FFV's Optimized for M85			Vehicles Optimized for M100		
	NMHC	MeOH	HCOH	NMHC	MeOH	HCOH	NMHC	MeOH	HCOH	NMHC	MeOH	HCOH	NMHC	MeOH	HCOH
Refuelling	0.7	0.0	0.007	0.53	0.0	0.005	0.19	0.7	0.06	0.15	0.5	0.035	0.05	0.5	0.015
Exhaust	0.28	0.0	0.0	0.18	0.0	0.0	0.058	0.122	0.0	0.058	0.122	0.0	0.0	0.03	0.0
Hot Soak/Diurnal	0.55	0.0	0.0	0.16	0.0	0.0	0.049	0.111	0.0	0.049	0.111	0.0	0.0	0.025	0.0
Running Loss	0.2	0.0	0.0	0.07	0.0	0.0	0.053	0.017	0.0	0.053	0.017	0.0	0.0	0.017	0.0
Refuelling	1.73	0.0	0.007	0.94	0.0	0.005	0.35	0.95	0.06	0.31	0.75	0.035	0.05	0.572	0.015
TOTAL															

SOURCE: Environmental Protection Agency, *Analysis of the Economic and Environmental Effects of Methanol as an Automotive Fuel*, Special Report (Ann Arbor, Michigan: Office of Mobile Sources, September 1989), p. 49.

TABLE 4.7
6V-92 METHANOL EMISSIONS

	HC	NO _x	CO	PART	ALDH
1991 Standards	1.3	5.0	15.5	0.1	
Demonstrated Engine-Out	0.7	2.3	2.0	0.08	0.08
With Optional Catalytic Converter	0.1	2.3	0.2	0.03	0.04

SOURCE: S.P. Miller, Detroit Diesel Corporation, "DDC Methanol Engine Development Status," paper presented at the 1990 Windsor Workshop on Alternative Fuels, sponsored by Energy, Mines and Resources Canada, U.S. Department of Energy and Ontario Ministry of Energy, by ORTECH International, Toronto, Ontario, June 11-14, 1990, p. 342.

If diesel fuel use is continued and standards are maintained by the transit and trucking industries, the implications will be numerous. Engine manufacturers could modify existing diesel engines to reduce nitrogen oxide levels, but in so doing would increase the emission of particulates. As well, modifying the engines to reduce NO_x levels would require the installation of expensive "traps" downstream in the exhaust system to reduce particulate emissions. New and improved diesel technology may provide a solution to this dilemma but, if not, the use of traps and the need for cleaner diesel fuels will add to the operating and maintenance costs of heavy-duty diesel vehicles. Heavy-duty methanol vehicles may therefore, in the end, prove less expensive to operate than diesel vehicles.

It is interesting to note, however, the results of a study prepared by SYPHER:MUELLER International Inc. for Energy, Mines and Resources Canada entitled the *Cost-Effectiveness of Alternative Transportation Fuels In Urban Buses*. In the current Canadian scene, because we have not yet adopted the tighter emission standards necessary to improve the environment, this report's conclusions suggest that the greatest improvements in emission reductions will still be made by fleets switching to newer technology diesel engines. Both cost effectiveness, through reduction in passenger loading capacity, and emissions levels were affected by the larger fuel tanks and volumes of fuel that were required on the methanol buses. Though both natural gas and methanol produced less particulate matter,

overall carbon monoxide levels were increased as extra buses were needed to overcome the reduction in carrying capacity.³⁴

4.6 Health and Safety Hazards

4.6.1 Toxicity

Methanol, like gasoline, is toxic and would, therefore, require some form of fuel marking (e.g., colouring) before it became widely sold as an automotive fuel. Ingestion of methanol can cause permanent damage to the central nervous system, blindness and, in extreme cases, even death.³⁵ Research analysis performed by the EPA in the United States suggests that methanol would not exceed the lower limits of concern (4.5 milligrams of methanol per cubic metre) specified by the United States Occupational Safety and Health Administration under normal moving traffic conditions. On the other hand, severe conditions in garages, for example, could greatly exceed this limit.³⁶

Benzene, a known carcinogen, is one of the toxic air contaminants emitted from the exhausts of gasoline and diesel fuelled vehicles. As emissions from methanol vehicles (using M85) contain benzene levels around one-seventh the levels emitted from gasoline, methanol use would make obvious improvements to the hazardous benzene levels being experienced today.³⁷

4.6.2 Flammability and Flame Luminosity

Transport Canada has recently investigated a number of safety issues concerning the use of methanol, gasoline, and diesel fuels, including flame visibility, the potential for fuel ignition on hot manifolds, and the flammability of vapours in fuel tanks. When flame visibility on various surfaces was evaluated, it was found that a methanol flame cannot be seen on surfaces where no other substance is burning. This hazardous characteristic must be rectified.

The potential hazard associated with fuel leaks in an engine compartment was assessed by dripping fuel onto a simulated hot manifold, and then onto a diesel exhaust manifold. Of the fuels tested, methanol with a cetane improver had the lowest ignition temperature of 450°C on the simulated hot manifold. Neat methanol and M85 exhibited ignition temperatures between 620 and 640°C. The temperature limit of the apparatus prevented the determination of the surface ignition temperatures of gasoline and diesel fuels. In the tests

utilizing the diesel exhaust manifold, the diesel fuel ignited only sporadically at 700°C, whereas the cetane improved methanol ignited at a temperature as low as 300°C. None of the other fuels being tested, including 100 percent methanol, 100 percent gasoline, two low level methanol blends, M85, and 85 percent methanol/13 percent gasoline/2 percent butane, ignited at temperatures up to 700°C, which was the temperature limit of the apparatus.

Three ignition sources were used to investigate the flammability of vapours in fuel tanks: a spark inside the tank, a flame outside the tank, and a projectile. The results from the tests performed indicate that methanol fuel appears to pose a greater hazard in the case of ignition sources within the tank. Gasoline, on the other hand, presents a greater hazard when exposed to an open flame.

4.6.3 Spillage

The effects of methanol spills on terrestrial and aquatic ecosystems appear less serious than those of either gasoline or diesel fuels, as normal biodegradation of this alcohol is more rapid than for either of these hydrocarbons. Nevertheless, methanol spills can leave effects on terrestrial vegetation which persist for at least one year, and can also do substantial damage to aquatic ecosystems.

4.7 Economic Assessment

4.7.1 Demand

Methanol, a high octane, efficient, clean burning fuel with a large domestic supply base, is currently being evaluated by North American policy makers for its long-term potential as a replacement for petroleum-based fuels in the transportation market. The primary impetus for methanol's potential demand growth will likely stem from the environmental concerns of Canada's legislators.

The government-mandated elimination of lead content in gasoline, as well as volatility and aromatic restrictions, is forcing refiners to search for alternative octane-enhancers. As MTBE has the potential to provide the necessary enhancement and is acceptable to the refiners, the demand for this product is likely to continue to increase, despite the fact that in Canada a portion of this market is still being supplied by methylcyclopentadienyl manganese tricarbonyl (MMT), an antiknock agent banned in unleaded gasoline in the United States due to concerns over associated emissions of manganese.

If environmental concerns continue to be expressed in energy issues, the demand for methanol use in flexible fuel and dedicated vehicles will likely increase in the near term. Canadian vehicle standards, outlined in Appendix B, reflect government concern for the societal costs associated with current levels of pollutants being emitted from Canadian vehicles. Should the improvements in air quality attributed to methanol persuade governments to undertake further initiatives indicative of support for this alcohol, fuel methanol demand could increase fairly rapidly over the next decade. If, for example, methanol absorbed just 3.5 percent of the transportation market by the year 2000, over 3 billion litres of methanol would be required for the transportation industry alone. If 10 percent of the market was absorbed, 8.6 billion litres of methanol would be required.

4.7.2 Reliability of Supply

Canada's methanol output ranks it as one of the largest methanol-producing nations in the world. Approximately 85 percent of Canada's production is exported to the United States, Japan and Europe. Canada's three world scale producers, Novacor Chemicals Ltd., Celanese Canada Ltd., and Ocelot Industries Ltd. had a combined production level of 1.91 million tonnes (2.5 billion litres) in 1989. Domestic demand was approximately 250 thousand tonnes. Where in the past over supply has been a major concern, this is not the present situation, however, as expanded formaldehyde and MTBE markets continue to absorb the excess capacity.

As noted in Section 4.2.1, methanol can be produced from a number of sources including natural gas, coal and biomass. Canada possesses some 2746 billion cubic metres³⁸ of natural gas reserves and 6268 megatonnes of coal³⁹ reserves, in addition to ample biomass resources. Canadian methanol producers currently consume 80 billion cubic feet of natural gas annually in producing 10 percent of world methanol production.⁴⁰ Though Canada has vast alternative feedstock resources in the form of coal and biomass, the short-term prospects for using either of these to produce methanol do not appear to be promising at this time, as the production processes involved would be much more capital intensive.

There appears to be little reason for concern over the possibility of a feedstock shortage constraining the Canadian methanol industry in the short term. A problem could arise, however, if fuel supply was constrained by insufficient demand over the medium and

long term or MTBE markets continued expanding due to greater use in reformulated gasolines.

At present, methanol is being produced primarily for the chemical industry. Because of this, the purity levels are higher than those which would be required for fuel grade methanol. Historically, therefore, North American prices have reflected the production and transportation costs associated with chemical grade methanol produced in smaller plants (2500 metric tonnes per day size). Economies of scale would certainly be realized should the transportation industry provide demand requirements sufficient to justify building 10 000 tonnes per day fuel methanol plants. The lower production costs made possible by large-scale plants and fuel-grade product would allow producers to supply methanol to the transportation market at competitive prices.

4.7.3 Incentives

As in the case of natural gas, the alcohol fuel industry is still at the research, development and demonstration stage. Currently, total federal funding available for methanol research and development in Canada amounts to \$7.3 million, which is distributed among the following programs:

- (1) The Methanol Market Development/Demonstration Program concentrates on both light- and heavy-duty vehicles. With light-duty vehicles, attention is focussed on flexible fuel vehicles under cold climate conditions. As for heavy-duty vehicles, efforts are concentrated on expanding the work of project "MILE" (Methanol In Large Engines). The MILE program is designed to test the use of 100 percent methanol in heavy-duty truck and bus diesel engines in urban centres across Canada. Also of note, several bus manufacturers have expressed a desire to join the federal government in developing a methanol bus from an OEM. The fuelling infrastructure may also require support to create a viable network of stations to adequately demonstrate the economics, environmental benefits and technical readiness of methanol.
- (2) The Methanol Technical Program includes research and development, field trials and technical demonstrations addressed primarily at large engine development, regulations, and standards. Under this initiative, the MILE Program oversees the operation of two transit buses and two large truck fleets, with data collected on their fuel consumption, driveability, startability, emissions and operator acceptance. Field

trial efforts and further research and development may also extend to the adaptation of methanol to fuel cells.

4.7.4 Empirical Assessment of the Value of Methanol

The analytical results presented here are based on information gathered from experts as well as public and confidential data. As fuel methanol is new to the traditional fuel market-place, the costs of production, vehicles and stations, as well as prices, may well be subject to fluctuations and change.

4.7.4.1 Production Costs

Unlike the present production and refining costs attributed to natural gas and propane, historical methanol costs do not indicate the value of this alcohol as a fuel supply source. The standard steam-methane reforming plants in existence today, which are designed to produce chemical grade methanol, have capacities of approximately 2500 tonnes per day. Recent studies performed by Bechtel, Inc. for a broad group of interested stakeholders and the United States Department of Energy suggest that increased demand levels in the next decade may result in plants being designed and built with capacities as high as 10 000 tonnes per day. Economies of scale and technological improvements would ultimately result in a reduced capital cost per litre of methanol produced. Table 4.8 projects the economies of scale likely to be achievable in Canada with increasing plant sizes and advanced technology, using domestic natural gas as feedstock. Even lower production costs are likely to be attained if remote or offshore gas, which would normally have been flared or reinjected, is utilized as an input. In these cases, the natural gas feedstock price would likely reflect only the cost of collecting and transporting the natural gas to the methanol refinery.

Canadian natural gas prices averaged \$2.58 per Mcf for industrial gas in 1989, \$1.44 per Mcf in Alberta and \$2.03 per Mcf in British Columbia. At \$1.50 per Mcf, feedstock prices would be 4.3 cents per litre.⁴¹ As natural gas prices rise in the future, domestic feedstock costs will also increase. Remote natural gas prices, however, are likely to rise more slowly due to the diversity of supply and the absence of competing markets.

Although methanol transportation costs were not considered in this analysis, larger domestic or export markets would benefit from

TABLE 4.8
ECONOMIES OF SCALE
ACHIEVABLE IN CANADA
1988-1998

Project Characteristics	2500 tpd	10 000 tpd
Methanol yield (litres/Mcf)	35	41.3
Methanol price (¢/L)	20	20
Production costs (¢/L):		
feedstock	4.3	3.6
other fixed plus variable costs	2.7	2.3
depreciation	2.7	2.9
Natural gas price (Mcf)	\$1.50	\$1.50
Debt/equity ratio	0/100	0/100
Tax rate (%)	44.8	44.8
Discount rate (%)	15	15
Project life (years)	10	10
Constant Canadian Dollars: Investment assumed made on July 1, 1990		

SOURCE: Canadian Energy Research Institute.

NOTE: Assumed natural gas price is delivered, and product price of methanol is plant gate. Converting the above to U.S. dollars using \$1.20 as the exchange rate yields:

Methanol price (¢/gal)	63.1	63.1
Production costs (¢/gal):		
feedstock	13.6	11.36
other fixed plus variable costs	8.5	7.25
depreciation	8.5	7.25
Natural gas price (\$/Mcf)	\$1.25	\$1.25

lower unit transportation costs because pipelines and dedicated ocean tankers would distribute the costs over large volumes of product.

4.7.4.2 Retail Market Value

Methanol is not currently being distributed to service stations for sale in the Canadian retail market. If and when methanol does arrive on the retail market, its price will be determined by the interaction of consumer demand and the price at which methanol producers are willing to supply their product.

Methanol has half the energy content of gasoline on a volume basis. But, it is a more energy efficient fuel. A five percent⁴² efficiency improvement is projected to be achievable with flexible fuelled vehicles, while dedicated methanol vehicles are expected to attain a 20 to 30 percent efficiency gain over gasoline. Consequently, flexible fuelled vehicles would require approximately 1.7 litres of methanol to travel the same distance as gasoline fuelled vehicles using one litre of gasoline, while dedicated M100 vehicles would require around 1.8 litres. Based on these ratios, Table 4.9 indicates the gasoline-equivalent methanol retail prices for M85 and M100, taking into consideration a differential attributed to energy content and efficiency.

TABLE 4.9
PRICING METHANOL BASED ON FUEL VALUE
(cents per litre)

	M85 As A Gasoline Substitute	M100 As A Diesel Substitute
Unleaded gasoline price	23.00	---
Diesel fuel price	---	24.00
Penalty for lower Btu content	12.35 ^a	9.79 ^b
Methanol value due to thermal efficiency	12.97 ^c	11.75 ^d

SOURCE: Canadian Energy Research Institute.

^aBtu content deficiency in relation to unleaded gasoline (23 × 0.537).

^bBtu content deficiency in relation to diesel fuel (24 × 0.408).

^cM85 is assumed to be 5 percent more efficient than gasoline.

^dM100 is assumed to be 20 percent more efficient than diesel.

The price differential available to methanol effects the payback time required to recover conversion costs (see Figure 4.8). Assuming constant price differentials of 15 cents per litre equivalent between gasoline and methanol and 6.5 cents per litre equivalent between methanol and diesel fuel, Figures 4.9 through 4.14 indicate the annual distance which must be travelled or levels of fuel consumption required to recover the incremental costs of buying a methanol light/medium vehicle, heavy-duty vehicle or bus over a reasonable time period. Conversely, Table 4.10 and Figures G.1 through G.4 indicate the effects that increases or decreases in the price differentials have on the time required to recover these same conversion costs.

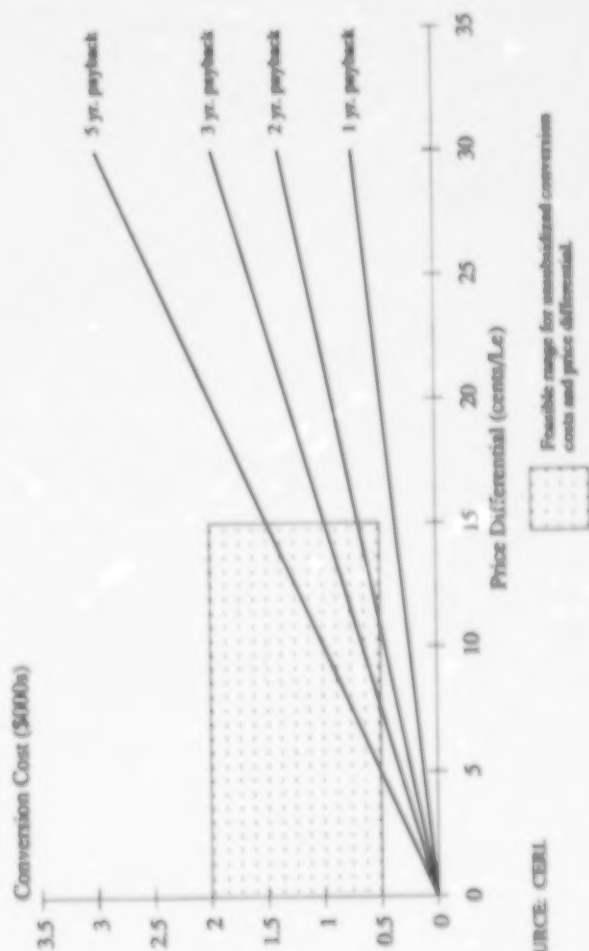
As with natural gas and propane, a favourable price differential will be necessary to persuade the consumer to switch to using methanol as a vehicle fuel. Although environmental issues are of a concern to most Canadians, it is unlikely consumers will be willing to switch to any alternative fuel if there is not some financial gain or at least compensation for the costs of conversion. Should the OEMs produce methanol vehicles at the same price as comparative vehicles operating on gasoline or diesel fuel, or government policies be established which would require "multi-vehicle owners" or "fleet vehicles" to operate one or more of their vehicles on cleaner burning fuels, then a positive price differential may not be required.

4.7.4.3 Incremental Vehicle Costs

Mass production of flexible fuel vehicles could conceivably lower the present incremental cost of these vehicles to around \$200. Dedicated methanol vehicles are likely to be produced at prices equivalent to those of gasoline powered vehicles. This analysis, however, considers incremental vehicle costs ranging from \$500 to \$2000 for both flexible fuel and dedicated vehicles (see Table 4.11).

It must be recognized that at these prices, the auto manufacturers are presently absorbing a fair share of the research and development costs. For a personal vehicle travelling 20 000 kilometres per year to pay back an incremental conversion cost of \$500 over two years, a price differential between methanol and gasoline of 11 cents per litre equivalent of gasoline is required. Heavy-duty trucks travelling 40 000 kilometres per year would require an 8.6 cents per litre equivalent price differential between fuel methanol and diesel to recover, in fuel savings, the optimistic incremental vehicle costs of \$2,200 per vehicle. Buses travelling 50 000 kilometres per year would

Figure 4.8
Payback Based on Conversion Cost and
Price Spread for L/M Vehicles



SOURCE: CEBL

Figure 4.9
Payback Based on Conversion Cost and
Annual Distance for L/M Vehicles

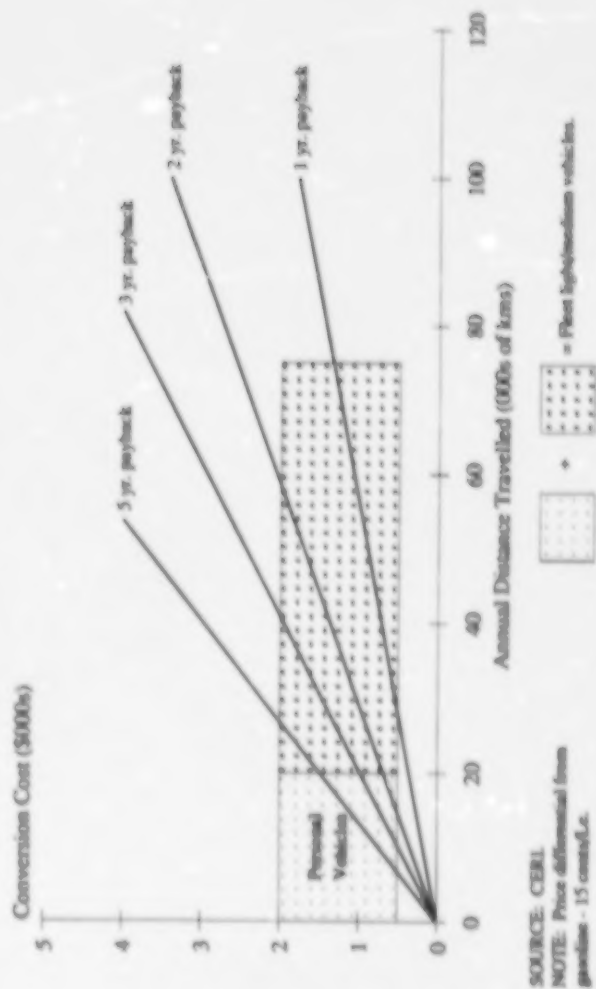
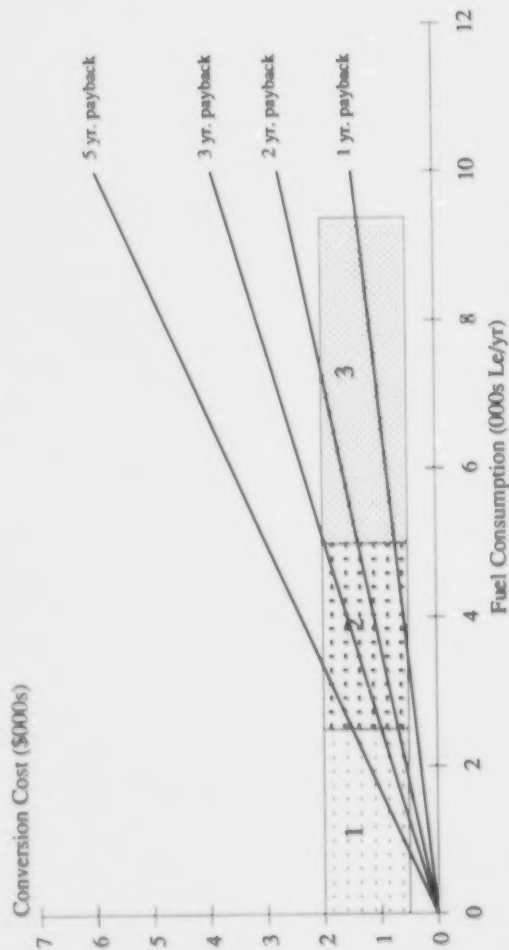


Figure 4.10
Payback Based on Conversion Cost and
Fuel Consumption for L/M Vehicles



SOURCE: CERL

NOTE: No station costs included.

- 1 - Typical personal vehicle fuel usage & conversion costs.
- 2 - Typical commercial vehicle fuel usage & conversion costs.
- 3 - Typical high mileage taxi fuel usage & conversion costs.

Figure 4.11
Payback Based on Conversion Cost and
Fuel Consumption for Heavy Vehicles

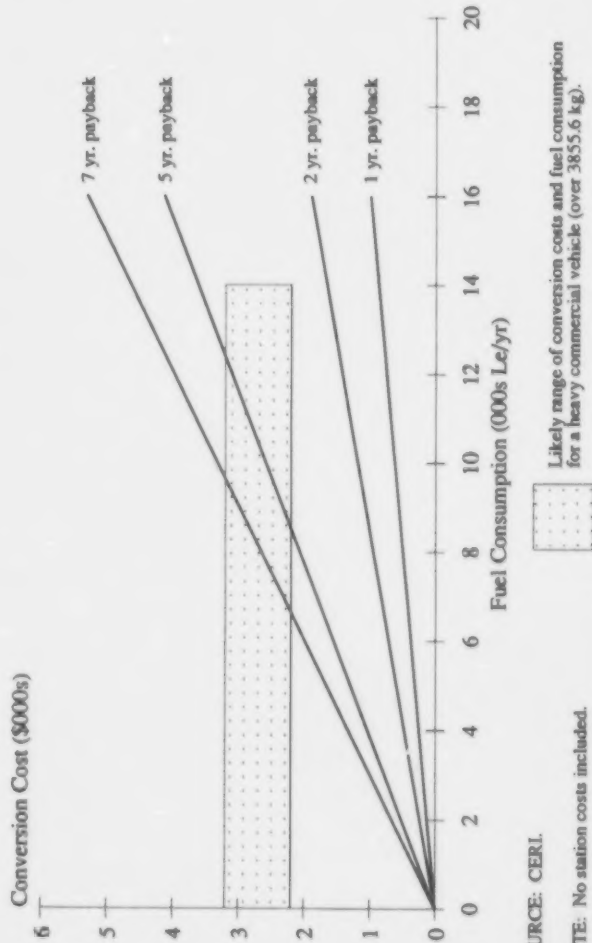
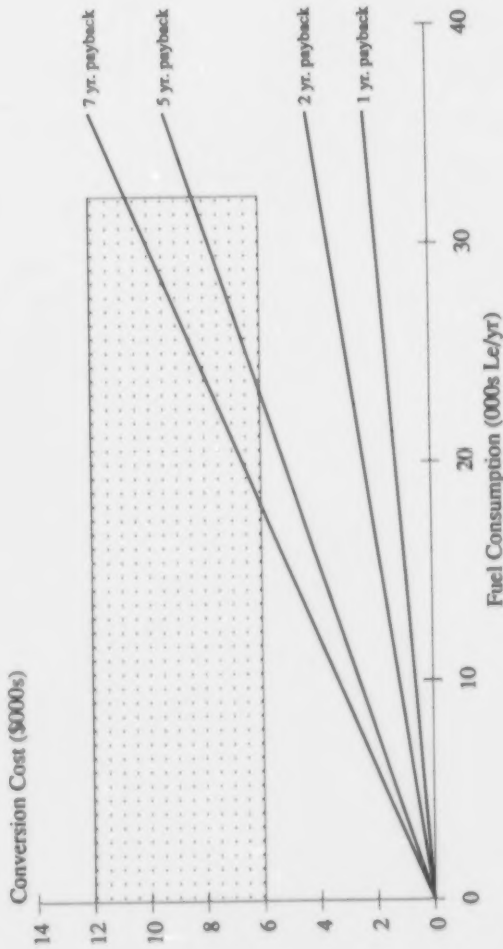


Figure 4.12
Payback Based on Conversion Cost and
Fuel Consumption for Heavy Vehicles

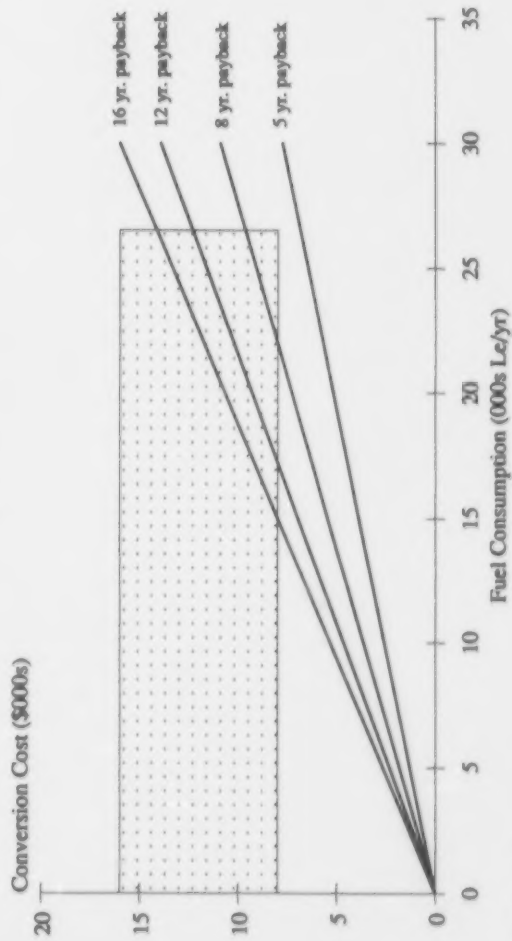


SOURCE: CERL.

NOTE: No station costs included.

Feasible range of conversion costs and fuel consumption for heavy vehicles (47000 kg).

Figure 4.13
Payback Based on Conversion Cost and
Fuel Consumption for Urban Buses

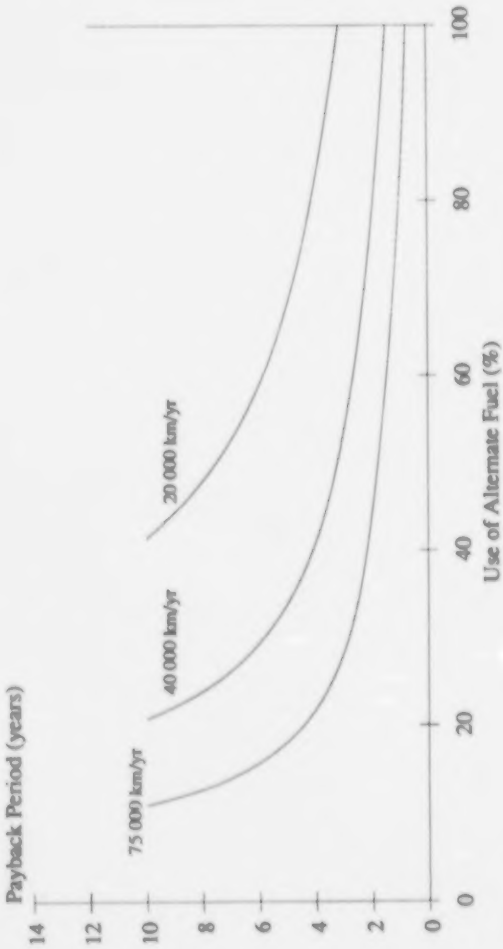


SOURCE: CERL

NOTE: No station costs included.

Feasible range for urban bus conversion costs and fuel consumption.

Figure 4.14
Effect of Varying Fuel Consumption
on Payback Period



SOURCE: CERL.

TABLE 4.10
EFFECTS OF PRICE DIFFERENTIAL
ON PAYBACK OF CONVERSION COST

	Assumptions			Price Differentials			Payback Period (years)
	Life (years)	Conversion Cost (Base Case \$)	km/yr	Le/1000 km	(¢/Le)		
L/M Personal Vehicles ^a	5	1,000	20 000	125	12.0 15.0 18.0	4.0 3.1 2.5	
L/M Fleet Vehicles ^a	5	1,000	75 000	125	12.0 15.0 18.0	0.9 0.7 0.6	
Heavy Vehicle > 3855.6 kg ^b	7	2,700	40 000	350	4.0 5.5 9.0	6.5 3.5 2.4	
Heavy Vehicle = 47 000 kg ^b	7	9,000	70 000	460	4.0 6.5 9.0	11.5 5.6 4.8	
Urban Bus ^b	16	12,000	50 000	530	4.0 6.5 9.0	7.3 11.5 6.9	

SOURCE: Canadian Energy Research Institute.

^aThe fuel savings calculated to determine the payback were discounted mid-year at 10 percent.

^bPrice differential from gasoline.

TABLE 4.11
LIFETIME FUEL SAVINGS FROM
METHANOL CONVERSION

	Assumptions			Conversion Costs			Fuel Savings	Net Benefit	
	L/100 km	km/yr	Life (years)	(\$)			Discounted (10%)	(\$)	
				Optimistic	Base	Pessimistic		Optimistic	Pessimistic
L/M Personal Vehicles ^a	12.5	20 000	5	500	1,000	2,000	1,491	991	491 (509)
L/M Fleet ^a	12.5	75 000	5	500	1,000	2,000	5,591	5091	4591 3,591
Heavy Vehicle > 3855.6 kg ^b	35	40 000	7	2,200	2,700	3,200	4,647	2,447	1,947 1,447
Heavy Vehicle ~ 47 000 kg ^b	46	70 000	7	6,000	9,000	12,000	10,687	4,687	1,687 (1,313)
Urban Bus ^b	53	50 000	16	8,000	12,000	16,000	14,134	6,134	2,134 (1,666)

SOURCE: Canadian Energy Research Institute.

NOTE: Net benefits do not include any infrastructure costs.

^aPrice Differential from gasoline is 15 cents per litre equivalent.

^bPrice Differential from diesel is 6.5 cents per litre equivalent.

require a 7 cent per litre equivalent price differential in order to recover the much higher incremental vehicle costs of \$12,000 per vehicle within ten years (see Figures G.5 through G.8). A further implicit cost of conversion in buses results from the reduction in passenger carrying capacity caused by the increase in fuel tank requirements.

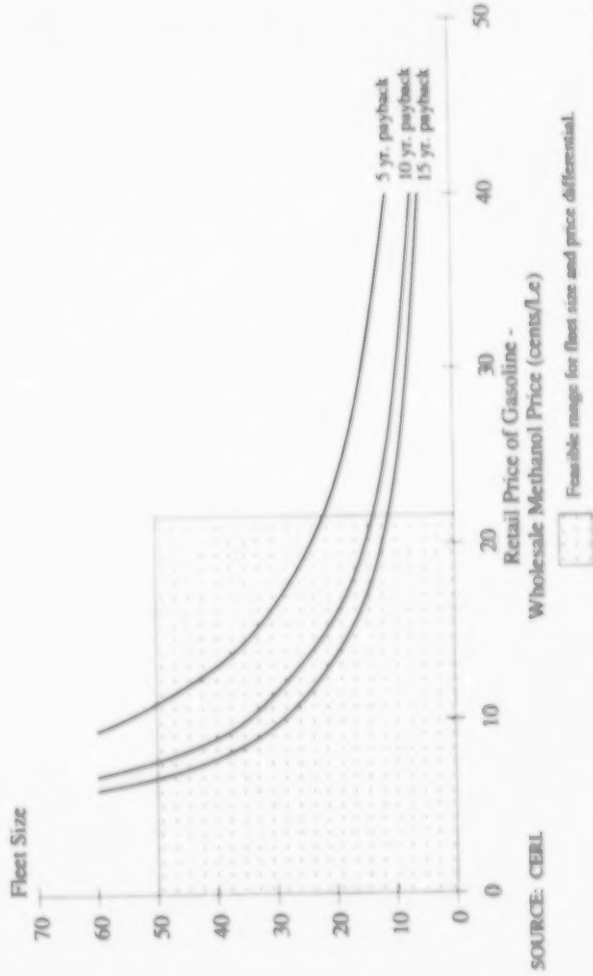
4.7.4.4 The Type of Operation: Single Vehicle, Small Commercial Fleet, or Large Commercial Fleet and the Fuelling Stations Costs

As with natural gas and propane, both the distance travelled annually and the volume of fuel consumed greatly affect the viability of changing over to the use of methanol (see Figure 4.14). When the costs of refuelling stations are incorporated into the analysis, the size of the vehicle fleet being converted is an important variable in determining the overall cost to the individual consumer or fleet manager (see Figure 4.15). In order for a fleet manager to recover both incremental vehicle costs and the capital investment for refuelling facilities, a fleet size of 26 vehicles would be required if the price spread between gasoline and methanol was 15 cents per litre equivalent; a fleet of over 61 vehicles would be required with a price differential of only 8 cents per litre equivalent. In other words, the wider is the price differential in favour of methanol, the smaller is the number of fleet vehicles necessary to recoup initial investments.

4.7.4.5 Environmental Incentives

Environmentally motivated government tax incentives could prove to be particularly vital to methanol's ability to compete with other alternative fuels and possibly capture a significant portion of the gasoline and diesel market. In the absence of such environmental considerations, it is likely that government policy makers will view methanol as simply another liquid vehicle fuel, one which should be subject to the same sort of tax treatment presently afforded gasoline and diesel fuel. Given current and projected methanol production costs, if this fuel was taxed so that the same proportion of its retail price constituted government revenue as is currently the case with the price of gasoline, methanol's cost advantage at the pump would be virtually eliminated, seriously hampering its capacity to attract new consumers (see Figure G.9). If, however, methanol was granted preferential tax treatment in light of its environmental advantages over current hydrocarbon fuels, then it would have a much better

Figure 4.15
Methanol L/M Fleet Economics,
Including Station Costs



chance of successfully gaining a larger share of the transportation fuel market.

Whether or not methanol's promise to provide emissions reductions warrants the forfeiting of what could be substantial tax revenue is, of course, a decision which must be made by the appropriate government legislators (see Figure G.10).

4.7.4.6 The Effect of Methanol Fuel Exports on Taxation and Retail Margins

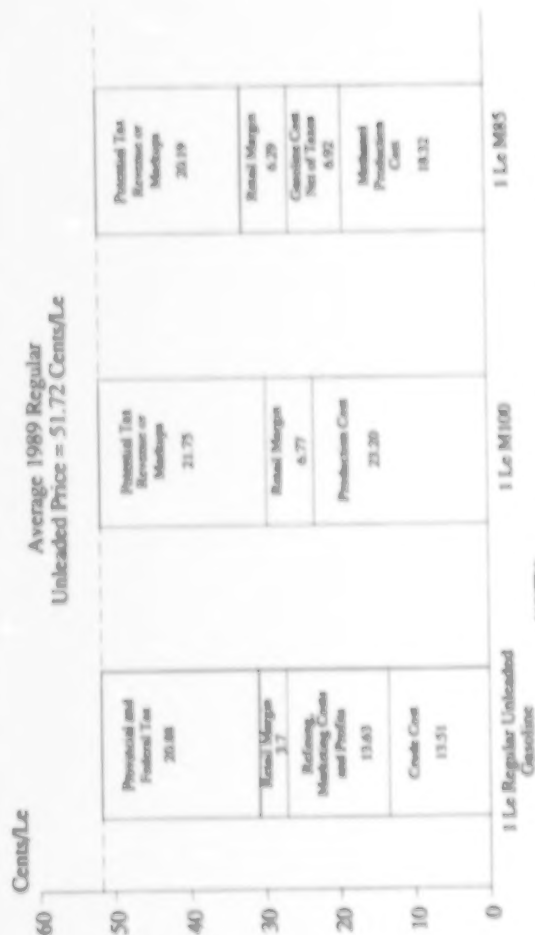
Canadian producers selling their product to the California Fuel Methanol Reserve this past year would have received between 40 cents and 43 cents (US) per US gallon or between 12.7 and 13.6 cents (Cdn) per litre. Assuming the 1989 combined average federal and provincial tax rate suggests that the Canadian tax revenue from these sales would range from 5.1 to 5.6 cents per litre of methanol exported. If this methanol were being sold into the Canadian transportation market in competition with gasoline, rather than being exported, then the tax revenue on a litre sold could be around 10.45 cents per litre. Assuming methanol can capture 3.5 percent of the transportation market by the year 2000, selling this alcohol in the United States rather than in Canada would suggest foregone Canadian tax revenue equal to \$358.5 million. However, as can be noted from Figure 4.16, the gasoline displaced by methanol would itself have generated almost equal Canadian tax revenue, thereby offsetting these tax implications. On the other hand, retail margins would be considerably higher from the sale of methanol in the Canadian market rather than the U.S. market.

4.8 Technological Advancements

Increased demand for fuel methanol may provide the impetus for development of larger methanol production facilities. Larger production facilities may, in turn, spur the development of emerging production technology--including catalytic partial oxidation, fluidized bed and liquid-phase synthesis--leading to reduced methanol prices via lower plant capital costs and higher process efficiencies.⁴³

Market growth may also result in coal and biomass feedstocks becoming economically viable alternatives to natural gas feedstock. Available estimates suggest that it currently costs between 18 and 29 cents per litre to produce methanol from coal. Although the production technology is fairly well developed, further refinements may be possible to bring production costs more in line with

Figure 4.16
Potential Tax Revenue from
Methanol Sales



NOTES:

M100 assumed to give a 20% efficiency premium over gasoline.

M85 assumed to give a 5% efficiency premium over gasoline.

SOURCE: CERL

conventional gasoline and diesel fuels. Further research into clean coal technologies will be necessary in order to meet more stringent environmental standards.

Research aimed towards developing an appropriate additive to resolve the aforementioned flame luminosity issue continues. Testing conducted under the MILE program has found that the methanol additive mixtures resulted in either fuel distillation effects or a low overall flame luminance.⁴⁴

In order to optimize methanol's fuel efficiency and emission characteristics, car manufacturers such as Ford, with their FFV, and General Motors, with their methanol variable fuel vehicle (VFFV), continue to develop methods which retain the range, cargo capacity and flexibility of refuelling currently enjoyed by their customers. The OEMs are also actively designing methanol engines for commercial applications in medium-duty trucks, school buses, and urban transit buses. Continued enhancement of these vehicles through additional testing, smog chamber studies and photochemical modelling analysis may provide the necessary enhancement required to inspire the buyers and remove the uncertainties faced by auto manufacturers.

One test program to be commended for its contributions to the understanding of the use of methanol as a fuel is the MILE project. Initiated in 1984, the project was designed to be an extensive trial of methanol fuelled compression-ignition engines in trucks and buses operating in regular fleet service across Canada. Methanol fuelled buses were evaluated in Winnipeg and Medicine Hat, and methanol fuelled heavy trucks were operated in Vancouver and on the long distance run between Coquitlam and the Alberta-British Columbia border. The four participating fleets each had two identical methanol vehicles which were matched against two similar diesel vehicles for performance comparison purposes. As support for the trial program, each fleet was provided with a custom-built methanol fuelling station, the appropriate safety equipment and personnel training, and the required repair and service backup. After almost one million kilometres of revenue earning fleet operations, SYPHER/MUELLER issued a report in May, 1990 for Energy, Mines and Resources Canada which cited the following results:

- (1) Due to continuing development by the engine manufacturers, the methanol vehicles were able to match the corresponding diesel units in terms of power, drivability and monthly availability.

- (2) On an energy basis, fuel consumption did not equal diesel levels.
- (3) Certain mechanical problems remained unresolved, including fuel injector tip blockage, glow plug durability and valve seat wear.
- (4) Indications were that long-term bearing and cylinder wear would be as good as a diesel engine.
- (5) Participating fleets and supporting engine dealers were able to fuel, service and maintain the vehicles and engines without undue difficulty, although the requirement for outdoor fuelling would be a problem for a large transit bus fleet.
- (6) The effect on servicing, repair work and safety measures was comparable to returning to the use of gasoline in heavy vehicles.
- (7) The most prominent safety and health issues raised were the low visibility of a methanol flame, and the concentration of aldehyde group hydrocarbons in the engine exhaust gases.
- (8) Exhaust emission reductions are possible, including the elimination of black smoke.
- (9) Economically, methanol fuelling is currently more expensive than diesel, but future developments resulting in lower methanol production costs and increased prices of diesel engines, fuel and equipment necessary to realise future exhaust emissions standards could make methanol cost effective.

The overall MILE project experience indicates that methanol is currently technically feasible as a heavy vehicle fuel.

4.9 Conclusions

Methanol is one of the leaders in the race to gain passenger vehicle market share for alternative fuels. Recognition of its potential to substitute for a portion of the fossil fuels being burned in automobiles while at the same time reducing the volumes of nitrogen oxides and reactive hydrocarbons being emitted into our atmosphere is driving its market growth. Methanol's appeal results from being a relatively inexpensive, clean burning liquid fuel and from a number of other factors, including the knowledge that there are currently available flexible fuel vehicles that can operate on a mixture of gasoline and up to 85 percent methanol (M85).

The financial analysis performed for this report indicates that methanol has the potential to compete in the transportation fuel market, particularly as a substitute for gasoline in light/medium vehicles. Continued research is necessary in the areas of flame visibility, and the environmental effects of methanol and formaldehyde emissions. However, with lead phased out of gasolines, flexible fuel vehicles attaining commercial production levels, gasoline prices increasing, and diesel quality continually decreasing, methanol may fare well as a gasoline and/or diesel substitute by the mid-1990s.

Footnotes

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³K. Morgan MacRae, *An Assessment of the Potential for Coal-Derived Syncrudes in Canada*, CERI Study No. 27 (Calgary, Alberta: Canadian Energy Research Institute, June 1988), p. xviii.

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⁵International Energy Agency, *Alcohols and Alcohol Blends as Motor Fuels*, Volume IIB, p. 9:13.

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¹¹United States Department of Energy, *Assessment of Costs and Benefits of Flexible and Alternative Fuel Use in the U.S. Transportation Sector. Progress Report One: Context and Analytical Framework* (Washington, D.C., January 1988), p. 20.

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¹⁹*Ibid.*, p. 222.

²⁰California Energy Commission, *Cost and Availability of Low-Emission Motor Vehicles and Fuels*, AB234 Report, Vol. 1 (California: Energy Technology Development Division, Technology Development Division, August 1989), p. 1.

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²⁶Energy, Mines and Resources Canada, *Cost-Effectiveness of Alternative Transportation Fuels In Urban Bus Operations*, p. 59.

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³¹U.S. Environmental Protection Agency, *Guidance on Estimating Motor Vehicle Emission Reductions from the Use of Alternative Fuels and Fuel Blends*, p. 21.

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³⁶*Ibid.*, p. 30.

³⁷California Energy Commission, *Fuels Report* (California: Fuels Planning Committee, November 1987), p. F-10.

³⁸Canadian Petroleum Association, *Statistical Handbook*, Section II, Table 7, July 1987.

³⁹K. Morgan MacRae, *An Assessment of the Potential for Coal-Derived Syncrudes in Canada*, CERI Study No. 27, p. 31.

⁴⁰Canadian Oxygenated Fuels Association, "Presentation to the Audit Committee of the Canadian Gas Association," overhead II, Edmonton, Alberta, May 18, 1988.

⁴¹Energy, Mines and Resources Canada, *Energy Statistics Handbook*, p. 7.18.

⁴²United States Environmental Protection Agency, *Analysis of the Economic and Environmental Effects of Methanol as an Automotive Fuel*, Special Report, p. 10.

⁴³*Ibid*, p. 3.

⁴⁴Energy, Mines and Resources Canada, *Demonstration of the Use of Methanol in Large Engines*, Project Report, prepared for Energy, Mines and Resources Canada by SYPHER:MUELLER International Inc., May 1990, p. VI-5.



Chapter 5

ETHANOL

5.1 Introduction

Ethanol produced from biomass is a renewable energy source with a high octane rating. With lead phaseout, this oxygenate becomes a candidate for use as an octane enhancer in the current gasoline pools, providing a premium liquid fuel from domestic resources as a partial substitute for conventional petroleum supplies. Presently, the ethanol produced in Canada is being marketed in low level gasoline blends. A neat or near-neat market for ethanol use in either dedicated or flexible fuel vehicles has yet to develop in Canada due in part to the high costs associated with its production.

The value of this fuel source to the transportation industry and the Canadian consumer is heavily dependent upon the following criteria:

- Petroleum Prices

Historically, high or unstable oil prices have generated initiatives directed at the development of more stable energy sources. In the past, when oil prices have been low, investors have for the most part been unwilling to become involved with the production of high cost fuels. Also, when situations such as the Iraq/Kuwait conflict occur and the accompanying concern for tightening oil supply has been resolved, oil prices usually decline and often to levels lower than those attained before the crisis began. As well, the time period for lower than average prices has a tendency to prevail longer than the upward swing in prices. This, in part, is due to the excess supplies generated by producing countries not only compensating for needed supplies but taking advantage of the opportunities for expanding their markets. The point to be made is that those interested in developing a fuel ethanol industry should not be motivated merely on the basis of the current trend of increasing oil prices, which has been artificially inflated due to political unrest. Rather, the industry should develop within the context of policy initiatives directed at the development of an environmentally positive, renewable energy supply source which has the potential to make this country less vulnerable to

politically instigated tightening of external crude supplies.

- Environmental Concerns

As leaner burning fuels, oxygenates have the potential to reduce carbon monoxide levels which are of particular concern in major urban centres. Also, ethanol produced from biomass may contribute to a reduction in the volume of carbon dioxide emissions attributed to the burning of fossil fuels. The rate at which CO_2 is added to the atmosphere with fossil fuels such as gasoline is much greater than the rate at which it can be reabsorbed and converted back into petroleum products. However, where ethanol is produced from cellulose and the by-product lignin used for process energy, the carbon dioxide produced from combustion of this fuel may, in fact, be reabsorbed almost as quickly as it is emitted. This would result in no net increase in CO_2 in the atmosphere.

- State of the Agricultural Industry

Current technology suggests that the feedstock requirements of an ethanol industry can be supplied by, and provide markets for, Canadian grains--in particular, those poorer grades which are more difficult to sell in the domestic and world market-place. The prevailing economic status of the agricultural community, therefore, has a direct bearing on the financial viability of grain-produced ethanol. The stability of the agricultural industry, however, is controlled by exogenous variables such as the climate, which affect the availability of supply and ultimately the cost of the ethanol feedstock, as well as fluctuations in consumer demand in both the domestic and export markets for grain and beef products.

- Octane Enhancer Versus Gasoline Extender

Oxygenates are oxygen-containing compounds such as alcohols or ethers which, when added to gasoline in small amounts, produce a blend known as "oxygenated gasoline". Octane enhancers are oxygenates that can be added to fuel to raise the octane number and therefore act as a substitute for tetraethyl lead. Gasoline extenders are those oxygenates which can themselves have value as a fuel, but are most commonly used as blending additives in greater volume than octane enhancers.

The value of ethanol as a fuel in the market-place is directly dependent on whether it is considered a gasoline extender or an octane enhancer. As a gasoline

extender, gasoline marketers would likely demand that fuel ethanol be priced at a substantial discount to gasoline. As an octane enhancer, the market value of ethanol should demand a higher price.

- The Pace of Ethanol Fuel Technology Advancement and the Extent to Which Cost-Effective Production is Developed.

The economic viability of using ethanol as an octane substitute for lead is highly dependent on the price of the fuel in the market-place. As feedstock costs contribute approximately half the value of the operating cost attributed to ethanol production, research and development into cheaper feedstock sources could greatly enhance the economics of an ethanol industry.

5.2 Technical Assessment

5.2.1 Production Technology

Ethanol (C_2H_5OH), also called ethyl or "grain" alcohol, can be derived chemically from ethylene, a product of oil refining; from ethane, a constituent of natural gas; or biochemically from fermentable sugars, derived from typical sugar or starch crops, cellulose, and other forms of biomass. Enzymes assist in the conversion of starches to sugars, which are then converted to ethanol through a fermentation process. For the fuel industry, the option of biochemical production is more appropriate since the chemical synthesis uses products already in high demand in the chemical industry.

The three stages of the fermentation process (which can, in fact, be applied to any material capable of being converted to ethanol) are as follows:

- the formation of a solution of fermentable sugars;
- the subsequent fermentation of this solution to a substrate called "beer", which contains dilute ethyl alcohol or ethanol in water; and
- the recovery of the ethanol from beer through distillation.

Additional process stages can be included to upgrade the beer and allow for the production of valuable by-products.

The three major types of biomass feedstocks used globally to produce ethanol include sugar crops, such as sugar cane and sugar

beets; starch crops, including barley, wheat, corn, potatoes and Jerusalem artichokes; and cellulosic materials, such as wood and crop residues. The choice of feedstock for an ethanol plant is dependent on a number of variables including:

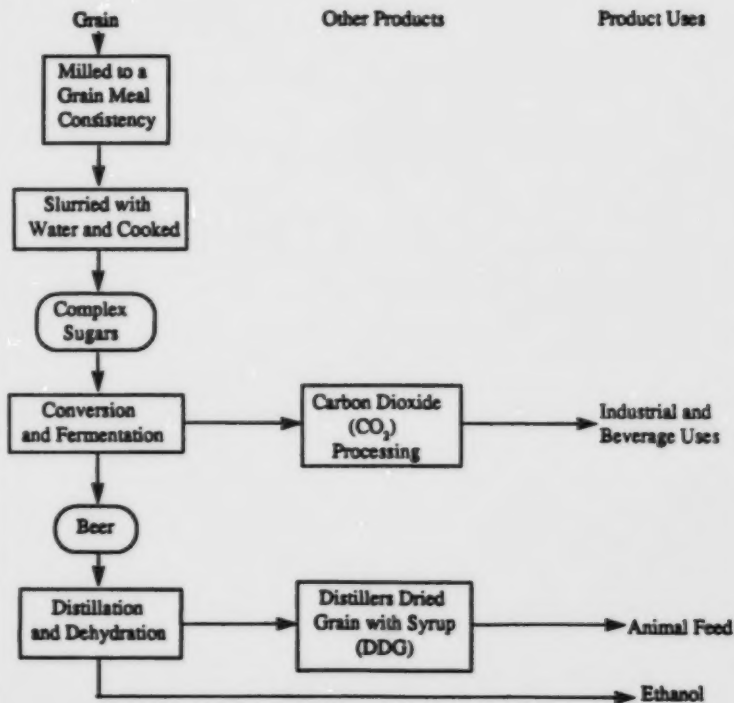
- the availability of feedstock and its proximity to the plant;
- the feedstock costs and their variability;
- the transportation and storage costs;
- the ethanol yield achievable per tonne of feed and per acre of land;
- the volatility of by-product prices and the stability of their markets; and
- the status of the available production technology.

Although the fermentation and ethanol recovery stages are similar for all feedstocks, the requirements for additional production stages to yield specific by-products are feedstock and site-specific, as well as market-oriented.

Currently, producing fuel ethanol from biomass relies on one of two grain processing technologies: dry or wet grain milling (see Figures 5.1 and 5.2). The dry milling process mills the grain, but does not separate its components before the "mashing" process. In addition to ethanol, a dry-milling plant yields a protein animal feed known as distiller's dried grains with solubles (DDGS), which can be further dried to become what is simply referred to as distiller's dried grains (DDG). Carbon dioxide, a by-product of both dry and wet milling, could also be collected for use in beverages, dry ice production or enhanced oil recovery. The ethanol, the DDGS or DDG, and the CO₂ produced each account for approximately one-third of the initial weight of the grain.

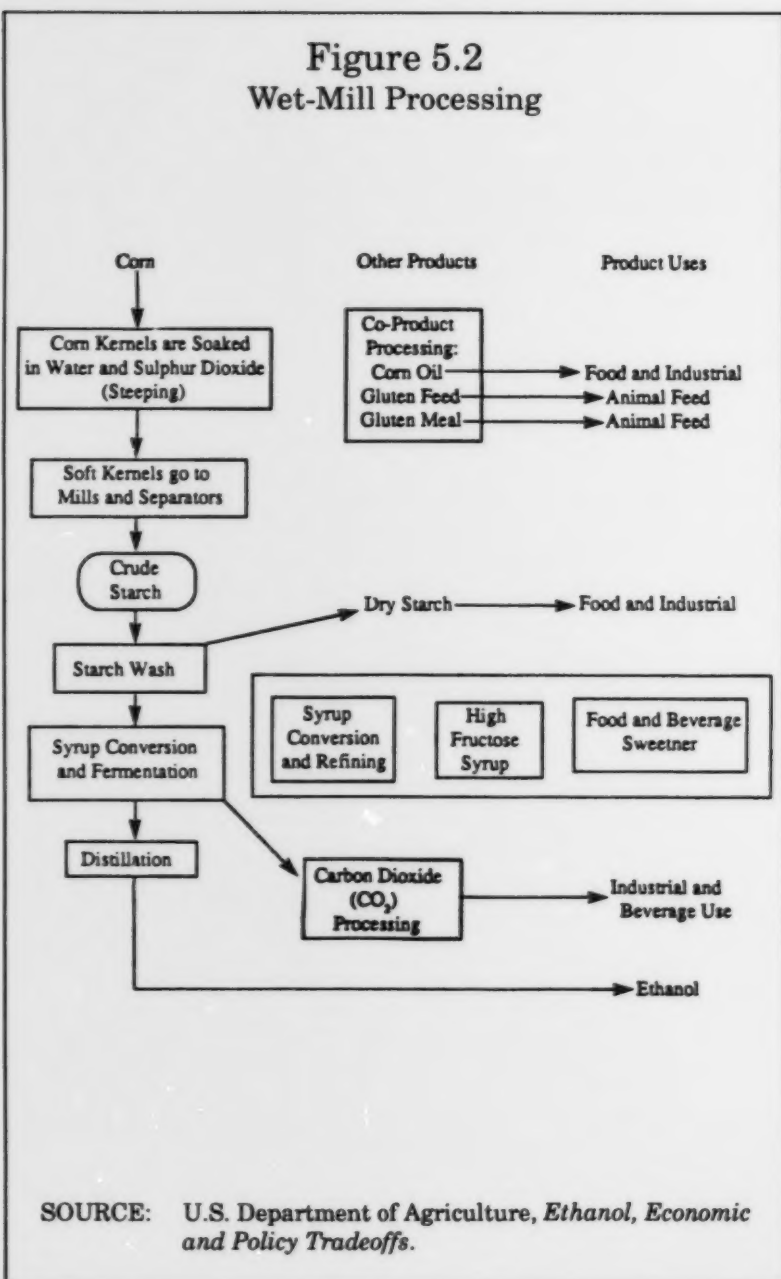
In the wet milling process, the feedstock is first divided into its major components such as germ, which can then be dried by separating out the oil, fibre, gluten and starch components. Depending on the demand and market price of each, the starch can be further converted into either ethanol or high fructose corn syrup. Though wet milling plants normally have more marketing flexibility, as they tend to produce higher value by-products such as corn gluten feed and meal,

Figure 5.1
Dry-Mill Processing



SOURCE: U.S. Department of Agriculture, *Ethanol, Economic and Policy Tradeoffs*.

Figure 5.2
Wet-Mill Processing



these plants are generally more complex and capital intensive than their dry milling counterparts.

5.2.2 Composition and Characteristics

Ethanol differs greatly from gasoline in its chemical makeup. Gasoline is composed of hundreds of different hydrocarbon compounds with differing properties, while ethanol, like methanol, is a single compound with well defined properties (Table A.1 outlines the physical characteristics of ethanol). These physical and chemical characteristics allow for the multiple uses of ethanol as a potable alcoholic beverage, a solvent or raw material in the chemical industry, an intermediate chemical in the making of pharmaceuticals, as well as a source of fuel.

Ethanol has a lower vapour pressure and higher heat of vapourization (about two-thirds that of methanol) than gasoline. This necessitates vehicle and/or fuel modifications similar to those described for a methanol vehicle, while it also provides the potential for lower evaporative and running loss emissions than experienced with either gasoline or methanol.^{1,2}

Although ethanol's energy density, or heating value, is about one-third greater than methanol's, a litre of ethanol contains only about two-thirds the Btu content of an equal volume of gasoline. This suggests that a FFV operating on 85 percent ethanol, 15 percent gasoline (E85) rather than M85 would be capable of a greater driving range, whereas the use of neat ethanol instead of gasoline would necessitate a 50 percent larger fuel tank (and a proportionate increase in fuel weight) or an increase in fuelling frequency.

Neat ethanol, as with neat methanol, has a high flashpoint relative to gasoline and broad flammability limits. The prevention of ignition from a spark or flame entering through the fill neck would require the installation of a flame arrestor on the fuel tank neck. An alternative to this would be the addition of gasoline components to prevent the formation of flammable vapours within the vehicle fuel tanks.

Ethanol's higher luminosity, greater energy density and lower heat of vapourization relative to methanol would suggest that ethanol would burn brighter, hotter and faster. On the other hand, ethanol's lower vapour pressure should counteract these effects.

Also, as with methanol, ethanol's low flame temperature, higher heat of vapourization, and tendency for lean combustion in comparison to gasoline, provide the potential for lower levels of NO_x emissions.³

The presence of water in ethanol fuel must be considered due to ethanol's affinity for water, which may cause phase separation and associated, operating problems. This affinity varies with temperature, the water content formula of the base gasoline, and the alcohol volume content.

5.2.3 Uses as a Petroleum Substitute

The economic value of ethanol as a gasoline or diesel fuel substitute in North America varies greatly, depending on whether it is used in neat or near-neat form or in a low level blend. The available commercial technology has high production costs, resulting in the need for government incentives to make even low level blends competitively viable. Even so, the concern for cleaner burning fuels and fuel additives has resulted in U.S. ethanol production for use in motor fuel blends reaching 840 million gallons in 1990.

Ethanol, recognized as an efficient, clean burning, high octane fuel (octane rating ranging from 100 as a "neat" fuel to 112 in blends),⁴ is also currently gaining interest from the Canadian transportation sector for the following potential uses.

5.2.3.1 Ethanol as an Octane Enhancer in Low Level Blends

Ethanol produced domestically for the fuel industry in Canada is being "splash blended" into gasoline in concentrations of 5 to 10 percent alcohol. These low level ethanol/gasoline blends can be used by vehicles originally designed to operate on gasoline to provide the octane enhancement required due to the phaseout of lead in Canadian gasolines.

In the United States, a number of refiners are reformulating their gasoline to include ethanol in order to provide the benefits of oxygenated fuels, namely, increased octane levels and lower carbon monoxide emissions.

5.2.3.2 Ethanol as a Raw Material in the Production of ETBE

ETBE is not economically competitive with MTBE without a major incentive such as the 60 cents (US) per US gallon ethanol blenders tax credit currently being provided by the United States Federal Government. However, ETBE's technical superiority (with equal or higher octane, lower vapour pressure and higher boiling point) will result in definite competition for MTBE if production costs can be lowered. Further, its low latent heat of vapourization precludes cold start problems and, like MTBE, ETBE provides pipeline fungibility and RVP reductions. As well, ETBE could be used to decrease VOC emissions and the resulting ozone formation. Presently, the U.S. EPA allows gasoline blends of up to 12.7 percent ETBE, which is equivalent to 5.77 percent ethanol in gasoline.⁵ Use of ETBE in Canada would open major new markets for ethanol.

	MTBE	ETBE
(R+M)/2	106-110	109-113
Vapour Pressure	10.5 psi	9.6 psi
Blending Vapour Pressure	8.0-8.5 psi	3.9-4.5 psi
Boiling Point	55°C	70°C

5.2.3.3 Ethanol as a Neat or Near-Neat Alternative for Gasoline in Dedicated or Flexible Fuel Vehicles

Continued reduction in the annual volume of pollutants currently being emitted into the atmosphere through further improvements in vehicle efficiency appear to be limited. If production costs can be lowered to be competitive with other alternatives, ethanol may provide an effective fuel substitute as its smaller molecules provide cleaner burning characteristics than gasoline.

5.2.3.4 Ethanol as a Substitute for Diesel Fuel

Heavy-duty vehicles have been identified as major contributors of atmospheric pollutants, particularly in urban areas. As mentioned earlier, the quality of diesel fuels is decreasing as the sulphur and aromatic content of these fuels increases. Diesel particulates, which carry carcinogenic components to the human lungs as well as reduce atmospheric visibility, result from incomplete combustion of the fuel. Engines designed to operate on ethanol, which burns free of

particulates, would provide an attractive option for meeting the new heavy-duty vehicle emissions standards proposed for 1991 and 1994 (see Table B.8), provided that production of the ethanol engines as well as the fuel do not prove to be too costly.

5.3 Performance and Compatibility with Current Vehicles and the Fuel Distribution System

5.3.1 Compatibility with Current Vehicles

5.3.1.1 Low Level Ethanol/Gasoline Blends

Vehicle manufacturers will honour vehicle warranties if ethanol-blend fuels are used. They recommend, however, that vehicle operators switch to straight gasoline if problems are experienced.

Testing in Canada has demonstrated that cars running on gasohol can obtain about the same fuel economy as when operating on gasoline. Conclusions from a fleet test, performed over a two year period by the Manitoba Department of Energy and Mines utilizing a 10 percent ethyl alcohol produced by Mohawk Oil Co. Ltd. and ESSO 2000 unleaded gasoline, suggested that "no engine modifications or adjustments were needed to convert standard gasoline powered vehicles to gasohol use and indicated no difference in specific fuel consumption for the two fleets".⁶

As noted earlier, a litre of ethanol contains about two-thirds the energy content of a litre of gasoline. This suggests a 3.3 percent increase in fuel consumption with the use of gasohol (10 percent ethanol, 90 percent gasoline). However, a recent report by the U.S. Department of Energy on the performance of alcohol gasoline blends concluded that gasohol fuelled vehicles averaged 4.7 percent fewer miles per gallon than gasoline fuelled vehicles.⁷ While this contradicts the results of the Manitoba fleet test mentioned earlier, there may be a reasonable explanation as evidence exists which suggests alcohol blends burn more efficiently in internal combustion engines than do gasolines.⁸ This would help offset any loss in heating value.

With low level ethanol blends, engine wear does not appear to be a concern, allowing the use of conventional lubricating oils. However, since ethanol is a solvent, first-time use of the blend often results in accumulated residues in the vehicle's fuel system being dislodged, thus clogging the fuel filter(s). This situation is easily

corrected by changing fuel filters. The newer the vehicle, the less the chance of this situation occurring.

5.3.1.2 Neat and Near-Neat Ethanol

Neat ethanol exhibits a superior resistance towards "knocking" when compared to many other fuels, and possesses even higher octane values when blended with gasoline. The knock resistance is believed to be improved by the high evaporative cooling effect, relative to that of hydrocarbons, as well as the high auto-ignition temperatures.⁹

As straight ethanol has different combustion properties from straight gasoline, burning it in engines designed for gasoline requires major modifications. The cylinder heads and carburetor should be modified for the higher compression ratio required to efficiently utilize ethanol's higher octane value and combustion properties. Also, specially designed materials have to be used for parts of the carburetor or fuel injectors, as ethanol would degrade some of the metals and elastomers that are compatible with gasoline. Fuel tanks would require the protection of an anticorrosive paint and a small gasoline tank may be necessary to overcome any cold start problems.¹⁰

Neat ethanol, like neat methanol, has a lower cetane number than conventional diesels and will therefore not "compression-ignite" on its own. Cetane improvers are available to induce compression ignition, but they are relatively expensive at this point and they negate some of the environmental benefits. Engines operating on enhanced ethanol require few modifications. Optimum performance will require injection volume and timing adjustments as well as larger pumps, lines and injectors.

Two other methods of using ethanol in compression-ignition engines are:

- (1) Dual-fuel systems involving:
 - emulsions of the two fuels;
 - fumigation, where introduction of the alcohol to the carburetor is accomplished by vapourizing the alcohol into the intake manifold; or
 - duel injection, which involves injecting the alcohol directly into the cylinder to be ignited by a pilot charge of diesel fuel.
- (2) Spark ignition of neat alcohols in diesel engines, which allows complete displacement of diesel fuel and makes

use of the high latent heat of vapourization of the alcohols and their high octane value. Excellent thermal efficiency and smooth combustion results from the high compression ratios and positive ignition.¹¹

5.3.2 Distribution

5.3.2.1 Transportation

Shipping ethanol through a common carrier pipeline creates several legitimate concerns for the refiner. For example, if a relatively "wet" fuel passes through the pipeline prior to sending through a batch of ethanol, the alcohol will simply absorb the water. Later, when the ethanol is blended with gasoline, phase separation can occur, causing driveability problems for any vehicle fuelled with the blend.

Another problem which can occur in the pipelines relates to the solvent properties of ethanol. Should ethanol be shipped through a common carrier pipeline, it may loosen some of the deposits which have precipitated out and line the pipes. This would not only result in contamination of the ethanol blend, but may contaminate subsequent products sent through the pipeline as well. It should be noted, however, that problems can exist in a pipeline when handling any two products, for example, crude oil and gasoline.

While sufficient technical experience has been gained to overcome the problems mentioned above, the complete solution would involve closer regulation of the pipeline delivery system itself. The pipeline would require thorough cleaning, and the water content of all products transported would have to be strictly regulated. An alternative solution might be dedicated pipelines for alcohol fuels. Whether the economics would justify such a system is another matter.

Ethanol can be transported effectively by both rail and truck. However, if either transport vehicle has carried a product other than alcohol prior to carrying ethanol, it must be cleaned and purged to prevent contamination of the ethanol product. Since this is standard industry practice whenever product switching is involved, it would not be a major obstacle to the effective distribution of ethanol.

There are also a number of regions in Canada where gasoline is shipped via barge. Again, problems can arise from water penetration/phase separation (for either ethanol or gasoline) unless there is consistent cleaning and draining of the tanks, piping and valves.

Dedicated vessels, designed to keep their cargos water-free, may be required.

5.3.2.2 Blending and Distributing

Canadian refiners and marketers are concerned about distributing a blended fuel of inferior standards and destroying customer confidence in their product. In order to ensure the Canadian General Standard Board standards are met with ethanol-blended fuels, the actual mixing and testing of the fuels should take place at the refinery. There are cases such as common carrier pipeline or marine transport, where intermediate transporting requirements may favour terminal blending. Under these circumstances, tailored gasoline may be prepared at the refinery and the gasoline and ethanol shipped separately to the terminal where they are blended. Increased costs would be incurred by the refiner due to the necessity of making and storing an additional grade or grades of gasoline. Although terminal blending of alcohol fuels can be achieved, there is a concern that quality control may be lost.

Pump blending for fuels containing ethanol may be uneconomical, as separate storage tanks would be required for the alcohol. Further, the pumps used to dispense the ethanol blend would require design changes to accurately blend the derived fuel. As tailored gasoline would be required for blending with the ethanol, separate storage facilities would also be needed for this product since it would be incompatible with the regular product sold at the pumps. This method of blending would not only be expensive but could leave refiners concerned that the quality of the blend would not be maintained, eventually resulting in unsatisfied customers and unfavourable publicity.

5.4 Vehicle Options

Flexible fuel vehicles designed to operate on gasoline or any ethanol-gasoline fuel mixtures containing up to 85 percent alcohol are currently being tested in Canada and, should production processes become more viable, will likely provide the solution for the use of near-neat ethanol-blend fuels until the necessary refuelling structure is in place. There is a chicken and egg problem here in that there is no refuelling structure in place because there has been no demand for the fuel. Flexible fuel vehicles, however, are not likely to exhibit the

potential savings which may be realized by dedicated vehicles due to the expense of the fuel sensor required.

An engine optimized to operate on neat ethanol is about 10 percent more efficient in converting energy to power, and can therefore be smaller and lighter than one designed to operate on gasoline. Other weight savings may result from the use of:

- a smaller catalytic converter, as most emission control systems use a specific ratio of catalyst volumes to engine displacement;
- a smaller radiator, as less heat is likely to be generated into the vehicle's cooling system than with gasoline; and
- a system for direct fuel injection to prevent cold starting problems rather than using a separate fuel system with a more volatile fuel, such as gasoline or propane, for starting before switching to the alcohol fuel.¹²

However, the redesigning of an optimized engine and vehicle is likely to involve both weight and cost reductions and increases, which could well equalize over the long term. For instance, direct fuel injection would add to the cost and the use of a larger fuel tank to carry volumes of ethanol equivalent to the driving range achievable on a comparable tank of gasoline would add to the weight.

5.5 Environmental Impacts

Environment Canada has recently announced that ethanol-blended gasoline is an "Environmental Choice" product. This allows distributors marketing such a product and meeting the requirements of the Canadian Environmental Protection Act to display the EcoLogo on the fuel dispensing pumps.¹³

Environment Canada determined ethanol-blended gasoline has lower carbon monoxide emissions than conventional gasolines but generally increased nitrogen oxide and aldehyde emissions. Three-way catalytic convertors used in newer technology vehicles are, however, effective in reducing carbon monoxide, aldehyde, hydrocarbon, and nitrogen oxide emissions.

Properly blended ethanol gasoline can reduce the aromatic content of the gasoline thus reducing the benzene emissions. Also, when produced from biomass, ethanol use provides a net reduction in

carbon dioxide emissions from fuel use, a major concern in global warming¹⁴ (see Table A.7).

Ethanol-blended fuels can substitute for lead as an octane booster and provide refiners with the antiknock enhancement necessary for their gasoline products. Also, should production economics become viable, ethanol could be used to fuel dedicated or flexible fuel vehicles and diesel powered urban buses.

5.5.1 Production Impacts

Commercial production of ethanol has been undertaken since ancient times and, when produced from biomass, has not resulted in any known environmental hazards of major concern. However, widespread use of ethanol as a vehicle fuel would require production on a scale far in excess of the quantities produced at present. Such an expansion of output could raise environmental concerns. Large-scale planting of dedicated crops for fuel would require good farming practices and assurances that the lands under cultivation were not needed for food production. Increases in soil salinity and the leaching of excess fertilizers and other chemicals such as herbicides and pesticides into the ground waters are other variables that would require continuous observation.

Combustion of fossil fuels is considered to have a major effect on global warming. The rate of CO₂ produced from burning gasoline and diesel fuel increases the volumes of CO₂ added to the atmosphere to levels potentially greater than can be reabsorbed by the earth's ecosystem. One of the environmental advantages attributed to ethanol produced from biomass has been its net reduction of CO₂ when the full production cycle is considered, as the CO₂ produced in combustion can be reabsorbed into new biomass feedstock.

5.5.2 Vehicular Emissions from Neat or Near-Neat Ethanol

5.5.2.1 Exhaust Emissions

Exhaust emission studies have concentrated on the effects of ethanol-blended fuels rather than on the effects of neat or near-neat ethanol. Whereas detailed modelling has been done in the United States on the effects of M85 and M100 on urban environments, corresponding data is not available for E85 or E100. In the absence of such research, the reactivity of emissions from ethanol fuelled vehicles relative to either gasoline or diesel fuel can only be estimated by

considering the reactivity of the major emissions which would be associated with ethanol combustion.

As with methanol, it is likely that the major environmental impact from ethanol fuelled vehicles would be its effects on urban ozone formation. Table 5.1 indicates the relative reactivities for methanol, formaldehyde, ethanol, and acetaldehyde as calculated by Ford Motor Company.

TABLE 5.1
REACTIVITIES PER CARBON^a

Compound	Based On Relative Reactivity
Ethanol	0.76-0.87
Methanol	0.69
Formaldehyde	2.31-3.72
Acetaldehyde	1.7-3.31
Gasoline NMHC	1.0

SOURCE: Environmental Protection Agency, *Analysis of the Economic and Environmental Effects of Ethanol as an Automotive Fuel*, Special Report, (Ann Arbor, Michigan: Office of Mobile Sources, April 1990), p. 45.

^aNormalized to gasoline NMHC carbon for easier comparison.

Comparison of relative reactivities provides the information necessary to determine the ozone-forming potential of organic emissions from ethanol fuelled vehicles relative to gasoline fuelled vehicles. Calculations by Ford, measuring the ozone-forming potential per carbon atom in gasoline versus ethanol, indicate that flexible fuel or dedicated vehicles operating on E85 or E100 would provide an ozone benefit compared to gasoline fuelled vehicles.¹⁵

Ethanol and acetaldehyde are emitted from ethanol fuelled vehicles. Acetaldehyde is highly reactive. The ozone impact of utilizing E85 or E100 is highly dependent on the surrounding atmosphere and the prevailing non-methane hydrocarbon to nitrogen oxide levels (NMHC/NO_x). According to the EPA, ethanol is more reactive than methanol at low and moderate NMHC/NO_x ratios, while ethanol is less reactive than methanol at higher NMHC/NO_x ratios.¹⁶

5.5.3 Vehicular Emissions from Ethanol/ Gasoline Low Level Blends

5.5.3.1 Exhaust Emission: HC, CO and NO_x

An oxygenated fuel blend of gasoline with 10 percent ethanol contributes to enleanment as a result of the oxygen present within the blend. Essentially, an oxygenate is a partially combusted hydrocarbon, as part of the process of oxidizing the components has already taken place. Therefore, if a gasoline containing an oxygenated component is fed into the cylinder of a conventional gasoline engine, the amount of oxygen required to complete the combustion process is less than for straight gasoline. As the amount of air taken into the cylinder is effectively the same as for a gasoline engine, the combustion effect in cars intended to run on gasoline is as though the mixture were lean. In other words, there is more oxygen available to complete the combustion than would be the case for straight gasoline. The effects of this enleanment are reduced exhaust emissions of HC and CO, but increased NO_x emissions.¹⁷

In a closed loop vehicle, which has an operating oxygen sensor in control of the engine, increasing the fuel flow until stoichiometry is achieved may compensate for the oxygen present in the fuel. In effect, this should result in a smaller absolute reduction in exhaust HC and CO emissions. Most of the CO produced from a closed-loop vehicle occurs during its occasional open-loop modes of operation.¹⁸

At higher altitudes, a given volume of air has lower density and less oxygen which generally results in greater HC and CO emissions. Both open loop vehicles and closed loop vehicles in their open modes will operate richer more often than they would at lower altitudes.¹⁹

5.5.3.2 Evaporative Emissions: HC

Adding ethanol to gasoline will result in a blend with a higher RVP than the base gasoline. This, in turn, will result in higher hot soak and "diurnal" emissions (see Table 5.2). Hot soak emissions, which arise both from the fuel metering system and the fuel tank, occur immediately after a vehicle is turned off. Carbureted vehicles have greater hot soak emissions than fuel injected vehicles. Diurnal emissions consist of hydrocarbons both evaporated and displaced from the vehicle's fuel tank. The increase in evaporative hydrocarbon emissions, combined with the increase in NO_x emissions, could create

TABLE 5.2
EVAPORATIVE VOC TECHNOLOGY-SPECIFIC^a
EFFECTS OF 10 PERCENT ETHANOL BLENDS^b
(percent change from gasoline)

	11.5 RVP Base		9.0 RVP Base	
	Same RVP	RVP + 0.76	Same RVP	RVP + 0.76
100 Percent Share (no commingling)				
Diurnal				
Carb.	-9.66	+80.10	-9.66	+41.13
F.I.	-9.66	+122.20	-9.66	+42.67
H.S.				
Carb.	+14.85	+35.28	+14.85	+25.52
F.I.	-5.70	+20.18	-5.70	+34.01
50 Percent Share (maximum commingling)				
Diurnal				
Carb.	+20.97	+96.21	-2.39	+51.72
F.I.	+33.92	+144.90	-3.32	+55.10
H.S.				
Carb.	+18.18	+39.57	+16.20	+28.47
F.I.	+1.57	+24.97	+0.30	+42.36

SOURCE: Environmental Protection Agency, *Guidance on Estimating Motor Emission Reductions From the Use of Alternative Fuels and Fuel Blends* (Ann Arbor, Michigan: U.S. Government Printing Office, Emission Control Technology Division, January 29, 1988), p. 36.

^aVOC - volatile organic compounds.

^bThese effects include adjustments for lower molecular weight of ethanol and lower number of carbons/gram relative to gasoline vapour. For hot soak (H.S.), adjustments for molecular weight are not used, but for carbureted vehicles an adjustment for distillation (percent evaporation at 160°F) is included.

ozone attainment problems in some areas during the summer months. However, if effective measures are taken to control the evaporative emissions from ethanol blends through tailoring the gasoline, or if ethanol usage is confined to cold weather seasons, then the usage of ethanol blends should not affect ambient ozone levels.²⁰

Current research suggests that aldehyde emissions increase when ethanol-blended fuels are burned, as both acetaldehyde and formaldehyde are produced. Aldehyde emissions have been found to be as much as 50 percent higher with blends than for straight gasoline. However, the extremely small amounts involved can be efficiently removed by catalysts, thereby reducing the possibility of negative health effects.²¹

5.6 Health and Safety Hazards

5.6.1 Toxicity

In comparing the major emissions from methanol fuelled vehicles versus ethanol fuelled vehicles, ethanol is less toxic than methanol and acetaldehyde is less carcinogenic than formaldehyde, suggesting that the overall toxicity of fuel ethanol is less than that of fuel methanol. In fact, concentrations of ethanol in the air of 1000 ppm and greater are required before symptoms such as headaches, irritation of the eyes and mucous membranes of the upper-respiratory tract, drowsiness, and the inability to concentrate become apparent.²²

Ethanol vehicles are expected to emit formaldehyde levels equal to or slightly greater than gasoline, but acetaldehyde emissions would be substantially greater in the absence of a catalyst optimized for aldehyde control. Peroxyacetyl nitrate (PAN), another pollutant related to fuel ethanol, is formed when acetaldehyde reacts in the atmosphere. As well as contributing to ozone formation, PAN can result in eye irritation and blurred vision at high enough concentrations, although these levels are unlikely to be reached in the atmosphere before ozone formation problems became apparent.²³

Polycyclic Organic Matter (POM), carcinogenic emissions from gasoline, will likely be close to nonexistent when burning E100, and possibly as much as 85 percent less when using E85.²⁴

5.6.2 Flammability

If ethanol is stored in closed containers, the combination of air and ethanol vapour above the liquid's surface is theoretically explosive at temperatures between 10 and 40°C.²⁵ Nevertheless, ethanol

can be stored in closed tanks without a protective atmosphere such as nitrogen because of its superb conductive properties which reduce the risk of static electricity leading to accidental ignition.

5.6.3 Transportation Hazards

Transporting ethanol in closed tank trailers could present certain risks, which can be reduced by installing flame arresters or vents. Another precautionary measure would be to transport the alcohol with some light hydrocarbons blended into the product, which would increase the saturated vapour concentration and lower its flammability limits. If the flashpoint of ethanol and gasoline are considered, spills of ethanol would appear to be less hazardous than those of gasoline. It should be noted that alcohol-resistant foams are available for fire fighting.

The effects on vegetation caused by ethanol spills remain at least one year which in most cases will cause a reduction in vegetation after contamination. However, there are no indications that the impact of an ethanol spill on vegetation would be more adverse than the impact of a gasoline spill.²⁶

Aquatic ecosystems can also be adversely affected if spillage occurs while transporting ethanol. But, as ethanol and methanol are soluble in water, concentrations are immediately reduced in the event of a spill. Since toxicity increases with the progression along the hydrocarbon chain, gasoline would pose higher toxicity risks to aquatic life than ethanol which, in turn, would pose higher toxicity risks than methanol.

5.7 Economic Assessment

Chapters 2, 3 and 4 of this study have concentrated on the viability of substituting high concentrations of natural gas, propane and methanol for use in motor vehicles. It is difficult to analyse ethanol in the same light as these three fuels, as production costs presently make it non-viable in its neat or near-neat form in the absence of very large subsidies. Ongoing research may eventually provide the technological improvements necessary to enzymatically convert high yielding cellulose to ethanol economically.

5.7.1 Demand

Demand for ethanol production is greatly affected by several uncertainties currently facing the Canadian energy and agricultural sectors:

- (1) Volatile oil prices and/or tightening energy supplies. Investment in ethanol production would quite obviously be more profitable if oil prices were higher and conventional oil supplies were tighter than at present.
- (2) Feedstock price fluctuations. The market value of the starch, sugar crop or lignocellulosic material used as a substrate for the biological production of ethanol has a definite impact on the competitive viability of fuel ethanol in relation to other alternatives. The higher the feedstock price, the higher the production costs of the ethanol, and ultimately the less competitive it becomes in relation to other fuels.
- (3) The demand for, and resulting value of, the by-products associated with the various ethanol production processes. This will have a major effect on the price and ultimately the demand for ethanol since the price at which ethanol can be economically sold as a fuel is affected by the amount of by-product credit added back to the cost of the feedstock.
- (4) The mandated removal of lead from Canadian fuel supplies, which may increase demand for ethanol as an octane enhancer in gasoline products. CGSB gasoline quality requirements for the transportation fuels of the next decade may leave a number of refineries octane short. Ethanol may be both an economically and/or environmentally competitive alternative to other investment options such as higher reforming or isomerization.
- (5) The current use of MMT as an antiknock agent in Canadian unleaded gasolines, which has a major effect on the value of ethanol as an octane enhancer. The EPA prohibits the use of MMT in American transportation fuels, and there have been indications that the United States motor vehicle manufacturers would like to see its use banned in Canada as well.

Manganese is listed as an air toxic in both the U.S. House and U.S. Senate approved clean air act amendments. Correspondence between the U.S. Health and the Environment and the U.S. Environmental Protection Agency suggest concern remains regarding demonstrations that manganese is capable of causing serious neurotoxic effects and damage to the human brain. As with lead, manganese

does not degrade or lose its potency with the passage of time.²⁷ Of concern is that MMT released in any given year will accumulate over time with MMT released in subsequent years resulting in hazardous air pollution.

Though MMT is highly toxic in its pure form and requires stringent safety guidelines at all stages of manufacturing, transportation and blending with gasoline, the CGSB has determined that the quantities of MMT allowed in Canadian fuels (0.072 grams per litre; 0.018 grams of manganese per litre) are not harmful to the environment or human health. However, should fuel standardization between the United States and Canada become a requirement in the near future, removal of MMT from Canadian fuels would create further disruption and octane deficits for this nation's refiners, providing an additional impetus for the use of ethanol as an octane improver.

- (6) Further restrictions on the allowable aromatic content of Canadian fuels would also have an impact on the octane requirements of refineries. If benzene is to be restricted, ethanol could provide a substitute for this octane stream.
- (7) Technological improvements which will result in a more cost-effective commodity, allowing ethanol to compete more equitably as an octane enhancer, a gasoline extender, a gasoline and/or diesel substitute, and a feedstock for ETBE.

5.7.2 Reliability of Supply

Canada is rich in productive farm lands, which are capable of producing the corn, wheat, barley and/or other raw materials necessary for ethanol production from biomass. Though Canadian farmers generally maintain that the requisite supplies could be produced to support an ethanol industry, Canada's gasoline refiners have reservations concerning the availability of a continuous and sufficient supply of ethanol to contribute to their octane requirements. Dedicated plantations or crops for the production of ethanol would definitely be required to assure the refiner of the consistent availability of ethanol, at prices competitive with other alternative octane sources as well as with foreign ethanol supplies. Even so, environmental hazards such as drought make the refiners' concerns valid.

In Canada, ethanol from biomass is currently being produced by a number of refiners:

- Mohawk Oil Company Limited produces 8.4 million litres of ethanol per year from the fermentation of grain at a converted distillery in Minnedosa, Manitoba. The capacity of this plant is in the process of being upgraded to 10 million litres per year.
- North West Food and Fuel Corporation has an ethanol plant in Saskatchewan which currently manufactures 1.5 million litres annually.
- Pound-Maker Investment Ltd., Mohawk Oil Company Limited and the Saskatchewan Wheat Pool have begun construction of a 10 million litre per year ethanol plant in Lanigan, Saskatchewan from locally grown grain.

If 10 percent ethanol were to be added to 15 percent of the entire Canadian unleaded gasoline pool, it would require an ethanol supply of approximately 54 million litres annually from 154 thousand tonnes of grain, assuming average yields of 350 litres per tonne. This represents roughly one quarter of one percent of the grain produced in Canada in 1990.

5.7.3 Incentives

Current environmental policies directed at greenhouse gas and ozone reduction, as well as the elimination of lead from gasoline, may indirectly promote increased demand for fuel grade alcohol produced from biomass. Octane supplies are tightening with the regulations presently being implemented and ethanol and/or ETBE have the potential to provide, and are definite candidates for, octane replacement.

The federal government has designated \$1,000,000 to the Ethanol Technical Program for expanding research on processes for the conversion of biomass to ethanol. An ethanol fuelled transit demonstration involving two buses is taking place in the Province of Saskatchewan where a 40 cents per litre incentive is in place for ethanol produced from Saskatchewan grain and marketed and sold in that province.

The provincial incentives in support of oxygenated fuels are:

- Alberta offers a 7 cents per litre tax rebate on the oxygenate portion of motor fuels.
- Saskatchewan provides a 4 cents per litre grant for a 10 percent ethanol blend (40 cents per litre of ethanol); however, if the distributor is marketing a blend of less

than 10 percent ethanol, a grant is paid in proportion to the amount of ethanol in the blend (i.e., if the blend contains 3 percent ethanol, the incentive is 1.2 cents per litre on the blend).

The incentive will be guaranteed to the distributor for each contract the distributor has with a producer. The guarantee period is four years and begins when the distributor first takes delivery of the ethanol from a producer. A participant in the Ethanol Production and Marketing Incentive Program also relinquishes participation in any additional provincial government support program such as the Venture Capital Program or SEDCO.

- Manitoba offers a 35 cents per litre rebate on ethanol containing not more than 1 percent water, derived from biomass, manufactured in Canada, denatured and in not less than 10 percent concentrations with gasoline.
- Ontario offers a full tax rebate on its 11.3 cents per litre road tax for the alcohol portion of a blended fuel.

5.7.4 Empirical Assessment of the Value of Ethanol

The current economic viability of ethanol as a neat or near-neat fuel is poor; however, in low level blends like gasohol or Mohawk's Premium Plus, ethanol's value as an octane enhancer may, in certain circumstances, represent a viable investment.

5.7.4.1 Production Costs

The cost of ethanol production for fuel use in Canada will vary considerably, depending on the site and size of the plant as well as the creative ingenuity of those operating it. Each plant is unique in its feedstock characteristics, feedstock costs, operating parameters, plant capacity, by-products and even product quality. Each producer has unique financial obligations such as debt-equity ratio assumed, the interest rates to be paid, as well as variable tax status.

Production costs can be lowered by locating the ethanol plant near:

- (i) the feedstock source, which may be:
 - corn or cereal grain,
 - fermentable wastes from a food processing or industrial facility, or

- pulp, if the technology can be developed to economically break the cellulose down to fermentable sugars;
- (ii) a feedlot where the by-products can be fed directly to the cattle, saving drying, transportation and marketing costs; and
- (iii) a petroleum refinery, where the ethanol can be blended with gasoline.

Promoting an ethanol industry as an agricultural diversification project requires plants with the capacity to produce around 10 million litres annually in order to achieve some economies of scale and still allow the animal feed by-product to be completely utilized in an integrated feedlot. However, to promote the use of ethanol as a fuel on a national basis requires larger, commercial scale facilities with production capacities of 50, 100 or even 200 million litres per year. Larger producers will have an inherent advantage over smaller producers in terms of their ability to more effectively market the fuel as well as realize production cost savings related to economies of scale. But, larger producers may not be able to achieve the full by-product credit available to an integrated feedlot.

A study published by the Canadian Energy Research Institute in 1989, based on the assumptions outlined in Table 5.3, determined that the current prospects for a viable ethanol industry in Canada (on a stand-alone basis) do not appear positive.²⁸ As wet milling is more expensive than dry milling, it was assumed that the primary process used is the dry milling process. The empirical assessment performed was based on data gathered from consultations with a number of producers as well as numerous public and confidential studies.

Even under the optimistic scenarios where ethanol would sell at 45 cents per litre and operating and capital costs are low, the 10 and 50 million litres per year plants fail to pay out, requiring revenues ranging from 61 cents to 65 cents per litre to reach pay out. The 100 million litre plant attains a 4 percent rate of return, and the 200 million litre plant a 7 percent rate of return, after ten years on stream. These last two plants require unit revenues of 59 and 58 cents, respectively (see Table 5.4).

The larger plants appear to be more viable than the smaller plants, benefiting from a savings of 5 to 6 cents per litre on the

TABLE 5.3

FINANCIAL EVALUATION
PROJECT CHARACTERISTICS OF BASE CASES, 1988-1998^{a,b,c}
 (10, 50, 100 and 200 litre per yr refineries)

	Pessimistic	Mid-Range	Optimistic
<u>Assumptions</u>			
Ethanol yield (litres/tonne)	350	350	350
Ethanol price (\$/litre)	0.35	0.40	0.45
DDG price (\$/tonne)	170	170	170
Feedstock cost (\$/tonne)	110	110	110
Tax rate (%)	44.8	44.8	44.8
Debt/Equity ratio	0/100	0/100	0/100
DCF Return on Investment (%)	15	15	15
Project life (years)	10	10	10
<u>10 mm litres/year</u>			
Operating costs (\$000s) ^d	56,457	54,557	51,707
Capital costs (\$000s)	15,000	12,000	10,000
<u>50 mm litres/year</u>			
Operating costs (\$000s) ^d	268,036	258,536	244,286
Capital costs (\$000s)	75,000	55,000	35,000
<u>100 mm litres/year</u>			
Operating costs (\$000s) ^d	517,071	498,071	469,571
Capital costs (\$000s)	115,000	90,000	65,000
<u>200 mm litres/year</u>			
Operating costs (\$000s) ^d	1,015,143	977,143	920,143
Capital costs (\$000s)	200,000	160,000	120,000

SOURCE: Canadian Energy Research Institute.

^aCO₂ assumed not sold, amounts given in constant Canadian dollars, investments assumed to be made on July 1, 1988.

^bOperating costs include feedstock plus "other" costs, but exclude depreciation.

^cThe variables changing in the base cases are the ethanol price and the capital and operating costs.

^dOperating and capital cost figures are cumulative over the ten-year life of the plant.

TABLE 5.4

UNIT REVENUES, 1988-1998^a
(10, 50, 100, 200 million litres per yr plants)

	Pessimistic	Mid-Range	Optimistic
Unit Revenues Achieved			
Unit ethanol price (\$)	0.350	0.400	0.450
Unit by-product price (\$)	0.155	0.155	0.155
Unit total revenue (\$)	0.505	0.555	0.605
Unit Revenues Required to Breakeven			
10 mm litres/year^b			
Operating costs (\$000s)	56,457	54,557	51,707
Capital costs (\$000s)	15,000	12,000	10,000
Taxes (\$000s)	--	--	750.45
Unit revenue required (\$) ^c	0.76	0.71	0.65
50 mm litres/year^d			
Operating costs (\$000s)	268,036	258,536	244,286
Capital costs (\$000s)	75,000	55,000	35,000
Taxes (\$000s)	--	--	11,382
Unit revenue required (\$) ^c	0.73	0.67	0.61
100 mm litres/year^e			
Operating costs (\$000s)	517,071	498,071	469,571
Capital costs (\$000s)	115,000	90,000	65,000
Taxes (\$000s)	--	826	24,758
Unit revenue required (\$) ^c	0.67	0.63	0.59
200 mm litres/year^f			
Operating costs (\$000s)	1,015,143	977,143	920,143
Capital costs (\$000s)	200,000	160,000	120,000
Taxes (\$000s)	--	5,380	59,004
Unit revenue required (\$) ^c	0.64	0.61	0.58

SOURCE: Canadian Energy Research Institute.

^aThe operating costs, capital costs and taxes presented are the consolidated costs over a ten-year life.

^b95 mm litres averaged over ten years.

^cUnit revenue required to achieve a payout by 1998.

^d475 mm litres averaged over ten years.

^e950 mm litres averaged over ten years.

^f1900 mm litres averaged over ten years.

operating costs and 5 to 8 cents per litre on the capital investment in comparison with, for example, the 10 million litre per year plant.

Table 5.5 reflects the same assumptions as in Table 5.3 with the exceptions being the feedstock cost (\$95 per tonne) and DDG price \$185 per tonne) (see Table H.1). These reflect the situation available to ethanol producers as of October 1990.²⁹

The grain market is extremely poor in Canada at present and farmers are concerned for their livelihoods. Integrated planning involving a series of smaller ethanol plants with possibly more than one feedlot may provide a market for their grains and stabilize their incomes. The size of the ethanol plants as well as the dimensions of the market they can sell to must, however, be well defined. Contracts from both the refiner and/or marketer buying the ethanol and the farmer providing the feedstock must be long term, and the feedlot business must be designed and managed to assure optimal by-product credit.

Though savings may be realized by designing more efficient plants which have lower operating costs and fuel consumption, the value of, or opportunity for, establishing an ethanol project is dependent on a number of other salient variables including: feedstock type, availability and cost; crop yields per acre and ethanol yield per tonne of feedstock (see Figure H.1); and an assured by-product market. To investigate the effect of changes on these key variables on the economic returns to an ethanol producer, a number of sensitivities were performed, the results of which are summarized in Tables H.1 through H.3.

5.7.4.2 Integration of Site, Feedstock and Feedlot

The by-product credit is crucial to the economic viability of an ethanol plant. For instance, crediting back the by-product revenue of 15.5 cents per litre of ethanol produced (based on selling the DDG for \$170 per tonne) to the 100 million litre per year optimistic plant analysis results in production costs of 43.5 cents rather than 59 cents per litre.

The integration of an ethanol plant using the dry milling process with a feedlot would prove beneficial. As both industries require the feed grain to be processed, savings could result from the need for only one processing facility. The distiller's grains, a highly

TABLE 5.5

UNIT REVENUES, 1988-1998^a
 ALTERNATIVE FEEDSTOCK COST AND
 DDG PRICE ASSUMPTIONS
 (10, 50, 100, 200 million litres per yr plants)

	Pessimistic	Mid-Range	Optimistic
Unit Revenues Achieved			
Unit ethanol price (\$)	0.350	0.400	0.450
Unit by-product price (\$)	0.155	0.155	0.155
Unit total revenue (\$)	0.505	0.555	0.605
Unit Revenues Required to Breakeven			
10 mm litres/year^b			
Operating costs (\$000s)	52,386	50,486	47,636
Capital costs (\$000s)	15,000	12,000	10,000
Taxes (\$000s)	--	76	2,000
Unit revenue required (\$) ^c	0.71	0.66	0.63
50 mm litres/year^d			
Operating costs (\$000s)	247,679	238,179	223,929
Capital costs (\$000s)	75,000	55,000	35,000
Taxes (\$000s)	--	2,865	18,353
Unit revenue required (\$) ^e	0.68	0.62	0.58
100 mm litres/year^e			
Operating costs (\$000s)	476,357	457,357	428,857
Capital costs (\$000s)	115,000	90,000	65,000
Taxes (\$000s)	--	12,624	52,430
Unit revenue required (\$) ^f	0.62	0.59	0.58
200 mm litres/year^f			
Operating costs (\$000s)	933,714	895,714	838,714
Capital costs (\$000s)	200,000	160,000	120,000
Taxes (\$000s)	601	34,224	101,538
Unit revenue required (\$) ^g	0.60	0.57	0.56

SOURCE: Canadian Energy Research Institute.

^aThe operating costs, capital costs and taxes presented are the consolidated costs over a ten-year life.

^b95 mm litres averaged over ten years.

^cUnit revenue required to achieve a payout by 1998.

^d475 mm litres averaged over ten years.

^e950 mm litres averaged over ten years.

^f1900 mm litres averaged over ten years.

nutritious animal feed which would otherwise involve drying, shipping and storage costs, can be fed directly to the cattle in the feedlot (or feedlots) along with the thin stillage or sweetwater produced. The additional integration with a grain handling facility to assure storage space for excess feedstock in the off-season would also be beneficial. But, this will require a more efficient elevator system than is currently available. Sharing management, labour and technical resources as well as office space, utilities and equipment would result in extensive operating cost savings. (Figure 5.3 is an example of an integrated food/alcohol project developed by the J.R. Simplot Company. This plant is actually a waste treatment plant that produces ethanol as a by-product.)

Another example of a successful integrated regional scale ethanol-from-grain plant, which can produce ethanol at comparable prices to a very large corn wet milling plant,^{30,31} is the Reeve Agri-Energy plant in Kansas. This ethanol plant uses distressed grain as the raw material and the by-product feed ingredients and the warm waste water are used in the feedlot.

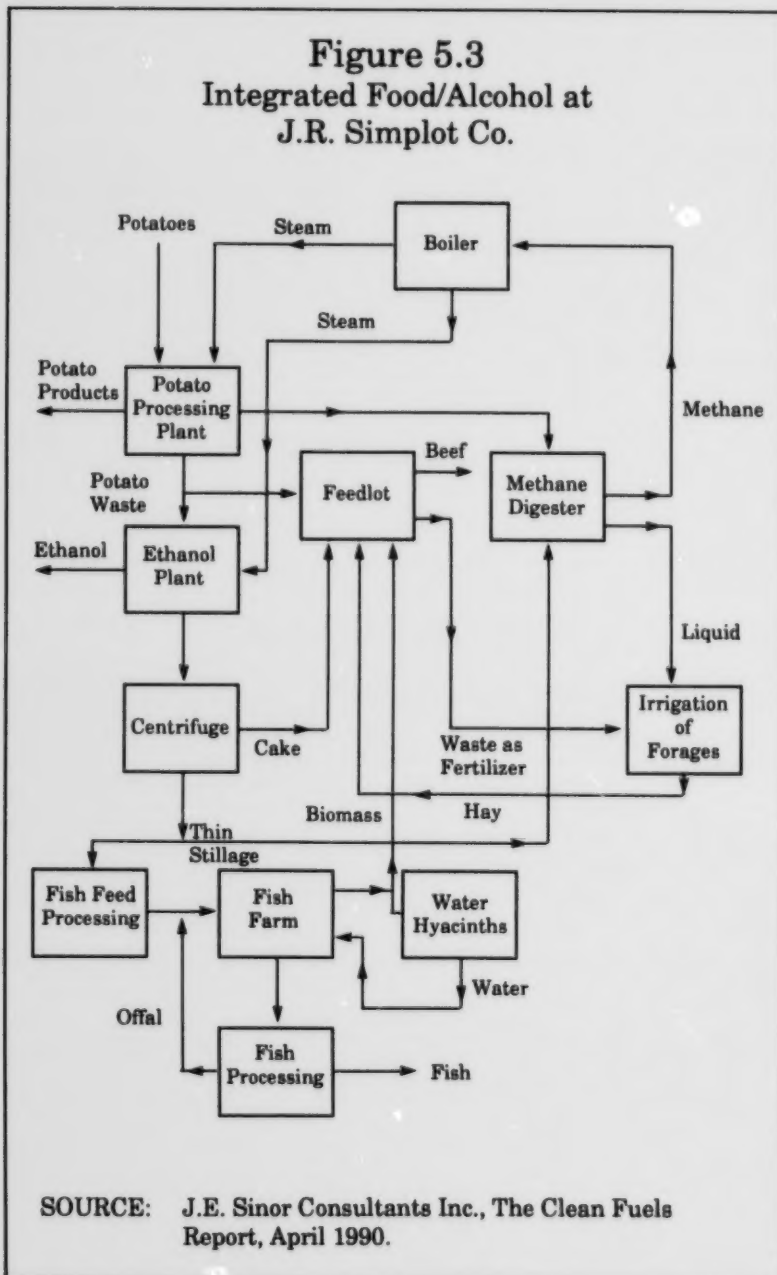
The Pound-Maker Feeds, Mohawk Oil Company and Saskatchewan Wheat Pool ethanol plant being constructed in Lanigan, Saskatchewan will be a good test for the integration concept. Neither the ethanol plant nor the feedlot are economical on a stand-alone basis. Projected cost savings from integration, however, suggest that the overall project will be profitable (see Table 5.6).³²

In recognition of the potential savings which would result from integration, the words "on a stand-alone basis" must be emphasized when suggesting ethanol production is not yet viable in Canada. In fact, this industry, which is dependent on such diverse markets as grain, livestock feed and energy, may become economically viable through optimizing the returns from its by-products by integration with a feedlot as well as an oil refiner and/or marketer having a petroleum refinery in proximity to the ethanol production facility, where the ethanol can be blended with gasoline.

5.7.4.3 Retail Market Value

As a fuel extender, ethanol contains two-thirds the energy content of gasoline, which ultimately results in reduced fuel volumetric efficiency. This suggests that to be economically competitive on a mileage basis, the effective price of ethanol should be around two-thirds the rack price of unleaded gasoline. However, with the octane

Figure 5.3
Integrated Food/Alcohol at
J.R. Simplot Co.



SOURCE: J.E. Sinor Consultants Inc., The Clean Fuels Report, April 1990.

TABLE 5.6
SAVINGS ATTRIBUTED TO INTEGRATING
AN ETHANOL-FROM-GRAIN PLANT WITH A FEEDLOT^{a,b}

Cost of Production (by-product credit taken at source)	43 cents
<u>Integrated Savings</u>	
Capital Cost Savings \$258,000 - 10 million litres	2.6
Operating Cost Savings \$1,005,000 - 10 million litres	10.0
Feed Savings \$330,000 - 10 million litres	<u>3.3</u>
	15.9
Cost of Production Possible in Integrated Facility	27.1¢/l

SOURCE: Coxworth, Ewen, "Outlook for Liquid Fuels from Biomass: Present Situation and Possible Future Opportunities," presentation at the Petro-Canada 1990 Environmental Conference, Calgary, Alberta, November 21-22, 1990 (from Shafer, 1988).

^aTo further examine the impact on our bottom line through integration let us look at the production costs of ethanol in cents per litre. It would be fair to say that a modern non-integrated facility of 10 million litres per year capacity could achieve an operating cost of approximately 43 cents per litre.

^bIf capable of producing at these costs the integrated facilities with even moderate improvements in technology and the oil price, we will be able to compete at the wholesale rack price of gasoline.

value of ethanol being 30 percent higher than regular gasoline, ethanol's value as an octane enhancer would be considerably greater than its value as a gasoline substitute. If the value of the ethanol blends in the market-place is to reflect the combined characteristics of a gasoline extender and an octane enhancer, its rack price could go as high as 29 cents per litre (see Table 5.7).

The volume of gasoline components (crude oil and butane) from the refinery, which must be replaced if the same product slate and volatility specifications are to be maintained, also affects the value of ethanol as a blended fuel. As crude oil is more expensive than butane, the higher the crude backout from the gasoline pool, the better the economics of the blended fuel. During the summer months, therefore, ethanol blends may result in more costly fuel because in order to maintain the CGSB volatility standards, ethanol's highly volatile nature would require tailoring of the base gasoline in a manner resulting in higher butane and lower crude backouts.

Table 5.8 indicates the incentives required to allow ethanol, with production costs ranging from 35 to 45 cents per litre, to be cost competitive in today's market with gasoline refinery costs of approximately 25 cents per litre.

It is important to recognize, however, that ethanol's potential value as an oxygenate would place the fuel in competition with reformulated gasolines which would have refinery costs approximately 1.3 cents per litre higher than the regular unleaded gasolines currently sold in the market-place.³³

5.8 Technological Advancements

Ethanol has the physical and chemical properties to be a good motor vehicle fuel or an octane substitute for lead if technological advancement can provide for a significant drop in its production costs and ultimately its market price. Feedstock costs contribute approximately half the value of the operating cost attributed to ethanol production, and so ongoing research directed at improving crop yield as well as determining cheaper feedstock sources (ones with high yield per acre as well as high starch content) could greatly enhance the economics of an ethanol industry.

A recent analysis by the Department of Agricultural Economics at Macdonald College,³⁴ investigating the costs of producing ethanol from Jerusalem artichokes, arrived at a production cost in Western Canada of 43 cents per litre of anhydrous fuel ethanol

TABLE 5.7
PRICING ETHANOL BLENDS
BASED ON FUEL VALUE
(1990 Cdn cents per litre)

	Gasohol	Premium Plus (+5% ethanol)
As a Gasoline Extender:		
1. Current rack price of unleaded gasoline ^a	23.00	26.00
2. Marketing Incentive ^b	1.00	1.00
3. Net Price of blended fuel	22.00	25.00
4. Price of gasoline portion	20.70	24.70
5. Required price of ethanol portion	13.00	6.00
As an Octane Enhancer:		
1. Current rack price of unleaded gasoline	23.00	26.00
2. Market value over unleaded gasoline (%) ^c	10	10
3. Price of blend	25.30	28.60
4. Price of gasoline portion ^d	22.77	27.17
5. Required price of ethanol portion ^e	25.30	28.60

SOURCE: Canadian Energy Research Institute.

^aAverage 1990 rack prices for the first six months.

^bThe "Pre-feasibility Study For A Comprehensive Alcohols Study for the Province of Alberta," done by St. Lawrence Starch Limited for Alberta Agriculture, suggested that selling ethanol as a gasoline extender in the marketplace may require a marketing incentive of one cent per litre.

^cAccording to the United States Department of Energy, in their January 1988 publication, *Assessment of Costs and Benefits of Flexible and Alternative Fuel Use in the U.S. Transportation Sector*, engines optimized to use ethanol should be about 10 percent more efficient.

^dThis calculation of the value of the gasoline in the blend assumes that the alcohol addition increases the value of the gasoline.

^eThe required price of the ethanol is obtained by taking: (3-4)/ethanol portion).

TABLE 5.8
ETHANOL - INCENTIVE REQUIREMENTS

	Gasoline	Ethanol	
Production Cost (¢/L)	25	45	35
Cost per Gasoline Litre Equivalent (¢)	25	67.4	52.4
Fuel Cost over Vehicle's Lifetime (discounted to present, five-year life) (\$)	2512	6694	5205
Optimistic Incremental Vehicle Costs (\$)	---	500	500
Total Costs over Vehicle's Life (NGV) (\$)	2512	7194	5705
Differential Costs (alternative fuel-gasoline) (\$)	---	4682	3193
Equivalent Incentive (¢/L)		31.5	21.5

SOURCE: Canadian Energy Research Institute.

EQUIVALENT INCENTIVES: Calculated as the amount by which production costs for these alternative fuels would have to be lowered in order to reduce "total costs over vehicle's life" to the level of gasoline.

produced and a net of by-product credit cost of 20 cents per litre when the alcohol is produced from the artichoke tops. Producing ethanol using the tubers resulted in much higher costs (gross \$1.06 per litre, net of by-product credits 86 cents per litre). The same analysis indicated much higher production costs in Eastern Canada (see Table 5.9). However, as an alternate feedstock source, Jerusalem artichokes have not yet been proven commercially viable.

TABLE 5.9
PRODUCTION COSTS/LITRE USING TUBERS
AND TOPS BY REGION

	Costs (\$/L)			
	Tubers ^a	Ethanol ^b	Tops ^a	Ethanol ^b
Quebec	87.1	1.01	30.83	0.36
Eastern Canada	130.9	1.48	67.35	0.72
Western Canada	72.5	0.86	15.30	0.20

SOURCE: Paul J. Thomassin, John C. Henning, and Laurie Baker, *A Pilot Study of the Economics of Fuel Ethanol Production in Canada, Based on Jerusalem Artichoke* (Ste. Anne de Bellevue, Quebec: MacDonald College of McGill University, 1990), p. 22.

^aTubers and Tops - \$ per tonne fresh weight basis.

^bEthanol - final production costs per litre net of by-product credits.

Although ethanol produced from lignocellulosic biomass such as trees, grass or waste paper products currently costs more to produce than ethanol made from wheat, barley or corn, developing Canadian biotechnology for the conversion of cellulose or hemicellulose to ethanol has the potential to lower the biomass conversion costs. This technology has not been commercially proven.

The absence of a cost-effective method of breaking the bonds between cellulose, hemicellulose and lignin has been the major drawback to the microbial conversion of lignocellulosics to ethanol. In 1989, the Saskatchewan Research Council published a study which examined the technical and economic feasibility of producing ethanol from cereal chaff, a cheap, renewable and under-utilized agricultural product with important bioenergy implications. A number of the currently available technologies for the conversion of lignocellulosics were examined and their economic implications outlined as follows:

(1) Stake Tech:

- Process: This approach "optimised the steam pretreatment of wheat chaff for the maximum hydrolyzability of cellulose to produce glucose and subsequently ethanol. Concurrently, optimization of feedstock fractionation, hemicellulose (pentosan) recovery, and the conversion of the pentosan stream to produce furfural or a xylose-rich syrup was also studied".³⁵
- Economic Conclusions: Ethanol production viability is dependent on plant capacity and the co-production of ethanol/furfural is an economic means of utilizing chaff.

(2) Iogen/Techtrol:

- Process: The Iogen process, which uses a patented steam explosion pretreatment, utilizes three distinct procedures including: "steam explosion pretreatment, novel biotechnology processing (including cellulase enzyme production and cellulose hydrolysis) and ethanol fermentation and distillation".³⁶
- Economic Conclusions: With molasses sold for 12.1 cents per kilogram, a chaff raw material price of \$10 per tonne, a lignin by-product credit of 10 cents per kilogram and existing enzyme technology, a 160 million litre per year plant could produce ethanol for approximately 61 cents per litre.

(3) Dr. Morris Wayman's Study:

- Process: "The technology assessed in this study employed the Wenger cooker-extruder for pretreatment. The pretreated chaff was then saccharified by acids and enzymes, the sugars thus produced being converted to ethanol by unique yeasts. As simultaneous saccharification-fermentation has been shown to give higher ethanol yields as well as major savings in process time and equipment, this process step was also evaluated for potential benefits".³⁷
- Economic Conclusions: The simultaneous saccharification-fermentation of the pretreated chaff resulted in a yield of 404 litres of ethanol per tonne of chaff. Dr. Wayman suggested that with a raw material cost of \$15 per tonne of chaff and a lignin by-product credit equal to its value as a fuel (\$.069 per kilogram), his process could result in ethanol which could be marketed at 24 cents per litre from a 20 million litre per year plant costing \$9 million to build.

(4) St. Lawrence Reactors Limited/BioHol Technology

- Process: "In the SLR process scheme, the three main components of biomass are isolated in a series of four steps which include prehydrolysis, delignification, hydrolysis (all hydrolyses use dilute hydrochloric acid as the catalyst) and fermentation. The latter step is accomplished via *Saccharomyces cerevisiae* fermentation of the hexoses while *Candida shehatae* and *Pichia stipitus* are used to convert the hemicellulose derived xylose to ethanol".³⁸
- Economic Conclusions: With a raw material cost of \$10 per tonne of chaff and a by-product credit for beverage grade CO₂ and single cell protein (equivalent to \$150 per tonne), a 20 million litre per year plant could produce ethanol for 23.3 cents per litre. A 40 million litre per year plant under this scenario was determined to produce ethanol for 20.1 cents per litre. Increasing chaff costs to \$15 per tonne and reducing the by-product credit to \$75 per tonne resulted in ethanol prices of 33.6 cents and 30.4 cents per litre, respectively.

Another study recently prepared by Entropy Associates, Inc. for Energy, Mines and Resources Canada examined the technical and economic assessment of the Iogen wood-to-ethanol bioconversion process.

The Iogen process is a "state-of-the-art process for the enzymatic conversion of the cellulosic fraction of woody feedstocks to ethanol, that features co-production of chemicals and animal feed from the lignin and xylose fractions".³⁹

The enzymatic hydrolysis process for making ethanol from biomass involves a number of steps: biomass production, pretreatment, enzyme production, enzymatic hydrolysis, fermentation, distillation, and by-product processing.⁴⁰ The two input streams in the Iogen process are wood, into the steam explosion pretreatment section, and lactose into the enzyme production section. Ethanol is the major output product with optional by-products from lignin and molasses.

In the base case, the economic results of which are indicated in Table 5.10, the lignin and molasses streams are dried and used as boiler fuel, providing process steam and electricity for the plant. Although conventional technology is used for the hydrolysis, fermentation, distillation and waste treatment in the plant, the

TABLE 5.10
ECONOMIC OUTPUT FOR IOGEN PROCESS

Cents/Litre	Units/Litre		Cents/Unit A Cost MM\$	
Wood (kg)	3.7	4.2	14.00	15.34
Cheese Whey (kg)	0.2	23.0	3.50	3.83
Lime (lb)	0.0	1.75	0.00	0.00
Chemicals	0.0		2.32	2.55
Utilities				
Water (1000 litres)	0.007	5.16	0.03	0.03
Steam	0.000	300.0	0.00	0.00
Labour (hr)	0.001	1540.0	1.87	2.05
Overhead & Maintenance			8.88	9.73
By-Products				
Xylanase (kg)	0.000	12.1	0.00	0.00
Lignin (kg)	0.000	22.0	0.00	0.00
Electricity (MW.h)	0.001	2920.0	<u>-2.40</u>	<u>-2.63</u>
Annual Operating Cost			28.20	30.90
Capital Charges			<u>15.64</u>	<u>17.14</u>
Ethanol Price			43.83	48.04

SOURCE: Department of Energy, Mines and Resources Canada, *A Technical and Economic Evaluation of Wood Conversion Processes: Volume II, Appendices*, prepared by; Larry J. Douglas, Entropy Associates, Inc.; the scientific authority was Jay Barclay, of Efficiency and Alternative Energy Technology Branch, Energy, Mines and Resources Canada (Ottawa, Ontario: Energy, Mines and Resources Canada, August 8, 1989).

pretreatment and enzyme production sections are unique to this process.

Pretreatment-steam explosion in this particular process--makes accessible the carbohydrate fraction of the biomass to enzymatic attack. The steam explosion, causing the release of lignin from the lignocellulosic matrix, produces a substitute that is easily hydrolyzed. A catalyst, in this case an enzyme, is then used to hydrolyze or convert the carbohydrate into fermentable sugar. The enzyme production section in the Iogen process uses lactose sugars from cheese whey as the substrate for enzyme growth. Enzyme production rates increase and enzyme production costs decrease when a liquid substrate is used. In fact, "the Iogen process has an enzyme growth rate that is five to ten times higher than conventional technology which uses cellulose as the carbon source for enzyme production".⁴¹

The base case results from consuming 1000 tonnes per day of aspen wood and producing 91 million litres of ethanol per year indicate an expected value for the ethanol price of approximately 48 cents per litre. As noted in Table 5.11, assuming lignin is valued at 22 cents per kilogram and molasses at 12.1 cents per kilogram, co-product credits could reduce the required value of the ethanol selling price to around 11 cents per litre. If the C5 sugars are converted to ethanol instead of molasses, the required selling price would be closer to 14 cents per litre. The ultimate potential of the Iogen process is determined by the co-product credit, without which it is doubtful any wood-to-ethanol process could compete commercially.

Continued research of the above nature is necessary if the commercial viability of this alcohol for use as a neat or near-neat fuel in the transportation sector is to be proven. Should one or the other of these processes be commercially proven, ethanol could potentially be produced at a cost below the rack price of gasoline.

Ongoing technological studies examining methods of reducing energy costs can also create dramatic advancements for the ethanol industry. The use of membrane technology for separating solubles could provide the ability to screen out 40 percent of the water before distillation, thereby reducing energy requirements.⁴²

Further examination into the value of the animal feed protein by-product as well as its processing requirements should also be undertaken. More appropriate utilization of the feedstock fibre, as

TABLE 5.11
POTENTIAL PROCESS IMPROVEMENTS

Process Step	Base Case	Improvement	Delta Ethanol Price
Enzyme productivity	400	1600	-5.61
Enzyme loading	25	10	-8.27
Glucose yield (%)	85	100	-7.47
Solids loading (%)	15	20	-2.83
Enzyme yield	250	400	-2.39
			<u>Ethanol Price (cents/litre)</u>
The net impact of summing these changes would result in an ethanol price of:			29.15
With co-product lignin at 22 cents per kg and			18.14
molasses at 12.1 cents per kg, the ethanol price			11.10
With xylose fermentation the ethanol price is and			21.00
with lignin co-product credit at 22 cents per kg			14.25

SOURCE: Department of Energy, Mines and Resources Canada, *A Technical and Economic Evaluation of Wood Conversion Processes: Volume I, Main Report*, prepared by Larry J. Douglas, Entropy Associates, Inc.; and Jay Barclay, Efficiency and Alternative Energy Technology Branch, Energy, Mines and Resources Canada (Ottawa, Ontario: Energy, Mines and Resources Canada, August 8, 1989).

well as the amino acids co-products produced in the ethanol manufacturing process, may also provide cost savings.

There may be potential for using cellulose treated in the same manner as animal feed. It would be fed in connection with wet distilled grain from a grain based ethanol plant but the natural effect would be the same as using cellulose for the ethanol plant and grain for the animal feed. This suggests cattle themselves may provide one of the best cellulose conversion processes currently available.⁴³

Development of a grain to be dedicated to alcohol production--one with a high yield per acre, high starch content, easy storage, less perishable than existing feedstocks, and possessing good co-product value--would obviously prove beneficial. The price of the feedstock could then be set at a level which would benefit both the farmer and the ethanol producer.

There are other technological advancements that could have a major impact on the desirability of an ethanol industry in Canada, but they require both time and money in the short term if Canadians are to gain an understanding of ethanol's long-run potential.

5.9 Conclusions

Ethanol produced from biomass is a renewable energy source which offers immediate prospects for providing a premium liquid fuel from domestic resources as a partial substitute for conventional petroleum supplies. The current economic viability of ethanol as a neat or near-neat fuel is poor. But, as an oxygenate with a high octane rating, it is a candidate for further growth in the Canadian transportation industry as a replacement for tetraethyl lead. If large-scale and cost-effective production techniques are not developed and proven commercially viable, ethanol is unlikely to develop in areas other than niche markets. This will hold unless (i) environmental issues (i.e., global warming) require mandatory implementation of an oxygenate program; (ii) energy self-sufficiency becomes a top priority issue; or (iii) political unrest such as that ongoing in the Middle East pushes crude oil prices back up to the \$40 per barrel range.

The market-place, which is currently influenced by environmental issues and supply concerns, will determine the ultimate long-term value of ethanol to the Canadian transportation sector. But, only capital investment and production and marketing experience, with government assistance if necessary, will provide the needed

practical insight into the potential economic and environmental benefits of ethanol utilization. Ethanol production and distribution will have to be just one part of a fully integrated system in order to minimize the risks associated with the development of a new industry and, at the same time, maximize returns.

Footnotes

¹United States Environmental Protection Agency, *Analysis of the Economic and Environmental Effects of Ethanol as an Automotive Fuel, Special Report*, Office of Mobile Sources (Ann Arbor, Michigan: Office of Mobile Services, April 1990), p. 8.

²The EPA adds the following in a footnote:

Although vapour pressure is an important factor in cold startability, the higher stoichiometric air:fuel mass ratio of ethanol (E100) and its higher molecular weight should combine to make the startability of ethanol closer to methanol (M100) than would be expected based only on their vapour pressures. The ratio of MeOH to EtOH stoichiometric A:F ratios (6.5/9.0), times the ratio of MeOH to EtOH molecular weights (32/46) gives about 0.5, indicating that the vapour pressure of the EtOH only needs to be half that of methanol to yield an equivalently combustible mixture. This does not take into account other dynamic factors such as the effects of heat of vapourization or lean combustion limits.

³Ibid., p. 10.

⁴Don O'Connor of Mohawk Oil Co. suggested the 112 reflects a 5 percent ethanol blend and pure methanol would be around 117.

⁵Agriculture Canada, *Grains 2000, Qualitative Assessment of the Canadian Commercial Transportation Fuel Ethanol Potential* (Winnipeg, Manitoba: National Grains Bureau, May 1990), p. 14.

⁶Energy, Mines and Resources Canada, *Gasohol and Propane Fleet Test*, prepared by N. Bercuson, D. Mathers, N. Bourdon, and L. Kozalk (Winnipeg, Manitoba: Industrial Technology/Manitoba Research Council, March 1983), p. 39.

⁷United States Department of Agriculture, *Fuel Ethanol and Agriculture: An Economic Assessment* (Washington, D.C.: U.S. Government Printing Office, August 1986), p. 4.

⁸Energy, Mines and Resources Canada, *Alcohol Additives, A New Opportunity In Transportation Fuels* (Ottawa, Ontario: Queens Printer, 1986), p. 12.

⁹International Energy Agency, *Alcohols and alcohol blends as motor fuels*, prepared by The Swedish Motor Fuel Technology Co. (Sweden: Swedish National Board for Technical Development, October 1986), p. 6:13.

¹⁰According to The Clean Fuels Report, published by J.E. Sinor Consultants Inc., April 1990, a neat-ethanol vehicle fleet test, to be performed by the University of Iowa, will utilize two neat-ethanol vehicles purchased from Brazil because these vehicles achieve satisfactory cold starts due to having a small auxiliary gasoline tank which supplies fuel for starting. The engine can be switched to ethanol

after a brief period. The program directors feel that the FFV being designed for California will not be adequate for use in Iowa because of poor starting characteristics in cold weather.

¹¹Ontario Ministry of Energy, *Alternative Transportation Fuels, Alcohol* (Downsview, Ontario: Transportation Energy Management Program, Ontario Ministry of Transportation and Communications 1985), pp. 15, 16.

¹²United States Environmental Protection Agency, *Analysis of the Economic and Environmental Effects of Ethanol as an Automotive Fuel, Special Report* (Ann Arbor, Michigan: Office of Mobile Sources, April 1990), pp. 34, 35.

¹³Department of the Environment, Canadian Environmental Protection Act. Section 8(1)(b).

¹⁴*Ibid.*, p. 5.

¹⁵United States Environmental Protection Agency, *Analysis of the Economic and Environmental Effects of Ethanol as an Automotive Fuel, Special Report*, p. 47.

¹⁶*Ibid.*, pp. 47, 48.

¹⁷United States, Environmental Protection Agency, *Guidance on Estimating Motor Vehicle Emission Reductions From the Use of Alternative Fuels and Fuel Blends*, prepared by the Emission Control Technology Division (Ann Arbor, Michigan: U.S. Environmental Protection Agency, January 29, 1988), p. 10.

¹⁸*Ibid.*, p. 10.

¹⁹*Ibid.*, pp. 10, 11.

²⁰United States, *National Advisory Panel on Cost-Effectiveness of Fuel Ethanol Production*, Final Report (Washington, D.C.: U.S. Government Printing Office, November 1987), pp. 4-18.

²¹The Royal Society of Canada, *Lead In Gasoline, Alternatives To Lead In Gasoline*, prepared by the Commission On Lead In The Environment (Ottawa, Ontario: The Royal Society of Canada, February 1986), p. 26.

²²International Energy Agency, *Alcohols and alcohol blends as motor fuels*, prepared by the Swedish Motor Fuel Technology Co. (SDAB) (Stockholm, Sweden: International Energy Agency, October 1986), p. 9:4.

²³United States Environmental Protection Agency, *Analysis of the Economic and Environmental Effects of Ethanol as an Automotive Fuel, Special Report*, p. 51.

²⁴*Ibid.*, p. 51.

²⁵International Energy Agency, *Alcohols and alcohol blends as motor fuels*, p. 9:12.

²⁶*Ibid.*, p. 9:11.

²⁷Correspondence between members of the U.S. Subcommittee on Health and the Environment and the U.S. Environmental Protection Agency, June 1990.

²⁸Michelle Heath, *Towards a Commercial Future: Ethanol & Methanol as Alternative Transportation Fuels*, CERI Study No. 29, (Calgary, Alberta: Canadian Energy Research Institute, January 1989).

²⁹Don O'Connor, Vice President Supply and Manufacturing, Mohawk Oil Co. Suggested DDG at \$185/tonne and feedstock at \$95/tonne would be indicative of the current-market.

³⁰Ewen Coxworth, "Outlook for Liquid Fuels from Biomass: Present Situation and Possible Future Opportunities," presentation at the Petro-Canada 1990 Environmental Conference, Calgary, Alberta, November 21-22, 1990, p. 3.

³¹According to Gavett, E.E. and Moffett, E., *Ethanol's Role in Clean Air*, USDA Backgrounder, U.S. Department of Agriculture, Washington, D.C., August 23, 1989, this plant is capable of producing ethanol for between 28 and 34 cents/L.

³²Ewen Coxworth and G. Olsen, *Feasibility of Regional Rural Processing Centres*, R-1520-2-E-90 (Draft) (Saskatoon, Saskatchewan: Saskatchewan Research Council, July 1990), pp. 16, 17.

³³Confidential Communication with one of Canada's large refiners. Although Arco's EC-1 gasoline currently has manufacturing costs as low as 1 or 2 cents US per US gallon, higher than conventional gasoline, it is believed costs will rise as the easy blending route is exhausted and more expensive manufacturing techniques must be used.

³⁴Paul J. Thomassin, John C. Henning, and Laurie Baker, *A Pilot Study of the Economics of Fuel Ethanol Production in Canada Based on Jerusalem Artichoke* (Ste. Anne de Bellevue, Quebec: Macdonald College of McGill University, 1990) pp. 19, 22.

³⁵Wayne Craig and Jack Kernan, *Examination of the Technical and Economic Feasibility of Producing Liquid Fuel Extenders and Additive from Cereal Chaff*, Publication R-811-1-E-89 (Saskatoon, Saskatchewan: Saskatchewan Research Council, March 1989), p. 42.

³⁶*Ibid.*, p. 62.

³⁷*Ibid.*, p. 70.

³⁸Ibid., p. 75.

³⁹Department of Energy, Mines and Resources Canada, *A Technical and Economic Evaluation of Wood Conversion Processes: Volume I, Main Report*, prepared by Larry J. Douglas, Entropy Associates, Inc. Lakewood CO, Scientific Authority, Jay Barclay, Efficiency and Alternative Energy, Technology Branch, Energy, Mines and Resources, Canada, Ottawa, Ontario, August 8, 1989, p. 4.

⁴⁰Brian Foody, *Ethanol from Biomass, the Factors Affecting Its Commercial Feasibility* (Ottawa, Ontario: Iogen Corporation, 1990), p. 1.

⁴¹Department of Energy, Mines and Resources Canada, *A Technical and Economic Evaluation of Wood Conversion Processes: Volume I, Main Report*, prepared by Larry J. Douglas, Entropy Associates, Inc. Lakewood CO, Scientific Authority, Jay Barclay, Efficiency and Alternative Energy, Technology Branch, Energy, Mines and Resources, Canada, Ottawa, Ontario, August 8, 1989, p. 13.

⁴²United States Environmental Protection Agency, *Analysis of the Economic and Environmental Effects of Ethanol as an Automotive Fuel, Special Report*, p. 21.

⁴³Don O'Connor, Vice President Supply and Manufacturing, Mohawk Oil Co.



Chapter 6

CONCLUSIONS

6.1 Introduction

Geographically, Canada is the largest country in the western hemisphere and the second largest country in the world. The wide expanse accentuates the importance of the transportation network to the Canadian economy, in a country where cars, trucks and buses help provide the framework for a culture defined by personal freedom and mobility. Yet, the automotive industry and the combustion of fossil fuels is being held responsible for much of the atmospheric pollution threatening the quality of the environment, particularly in our urban centres. As well, Canada's supply of conventional oil reserves is diminishing, and events in the Middle East are once again focussing concern on the issue of security of oil supply.

The above comments notwithstanding, petroleum-based fuels have been and will continue to be the backbone of the Canadian transportation industry for many decades to come. They are and will remain economic well into the next century. There will continue to be accessible supply sources. These fuels are efficient and maintain superior technical performance. They are convenient to transport and store both in the current vehicle fleet and for distribution. The infrastructure is in place to produce, refine, pipeline, truck or tank, and distribute both gasoline and diesel fuels.

Why then is a country rich in petroleum resources considering alternative fuel sources?

- **Security of Oil Supply**

Canada will not run out of oil for many decades to come. But, we do not have to run out to run short. The composition and quality of our crude resources are changing, placing constraints on the availability of inexpensive crude supplies as well as heavier demands on our producers and refiners to provide the upgrading and refining necessary to supply the petroleum products being demanded by our automotive industry. In addition, political unrest in the Middle East, which contains the bulk of the world's conventional petroleum supplies, is constraining access to relatively

inexpensive oil imports, resulting in a tightening of supplies and threatening to increase crude oil prices.

- Volatile Oil Prices

Over the next decade, security of crude oil supply appears of minor concern for most regions of our economy; however, that same time period may well be characterized by unstable oil prices as the OPEC member countries continue to manipulate prices by changing production rates. Historically, unstable oil prices and crude price shocks have generated interest in the development of more stable energy sources, **again alternative fuels.**

- Environmental Concerns

Environmental concerns are becoming important social and political issues in Canada. The deleterious effects of global warming, carbon monoxide, ozone and smog are resulting in the formation of policy initiatives aimed at resolving the quest for cleaner fuels.

Lead phaseout and an increasing demand for premium unleaded gasoline are resulting in the need for increased octane requirements or alternate energy sources. Canadian refineries are quite distinct from each other in their ability to enhance the streams entering their gasoline pools: while "high severity reforming" or "isomerization" may be the answer for some refiners, oxygenates such as ethanol, methyl tertiary butyl ether and ethyl tertiary butyl ether may provide a more viable option for others.

In general, the quality of diesel fuel is decreasing as the sulphur and aromatic content of these fuels increases. As the quantity and the quality of Canada's crude supplies are deteriorating, precautionary measures are being put in place to ensure environmentally safe upgrading of these fuels. However, natural gas and methanol are becoming attractive options for automobile manufacturers who must meet the U.S. EPA's stringent diesel emissions standards set to be staged into effect in 1991 and 1994.

- Agriculture Diversification

On average over the past five years, Canadian grain farmers have been faced with relatively low grain prices. Many of the countries which once imported Canadian grains and grain products have become self-sufficient and, in some cases, have established their own subsidized export programs. As the markets for our cereal grains decreased, so also did their prices,

leaving the Canadian agricultural community in serious need of further subsidies to support it.

Current technology suggests that the feedstock requirements of an ethanol industry may provide markets for Canada's grains, in particular those grades which are more difficult to sell in the domestic and world market-place. However, climatic uncertainties affecting the availability of grain supplies and ultimately ethanol feedstock costs have kept the refiners questioning the long-term supply potential of ethanol for the transportation market.

6.2 The Current Opportunities for Alternative Fuels in the Canadian Transportation Market

As outlined in Chapter 1, the opportunities for natural gas, propane, methanol and ethanol as alternative fuel sources in Canada will be dependent on their ability to meet the demands of the nation's transportation sector.

Alternative fuels must be environmentally acceptable.

When comparing the environmental effects of natural gas, propane, methanol and ethanol to gasoline and/or diesel fuel one must recognize that the emissions from any particular vehicle depend on a number of factors other than the fuel, including the condition of the engine and the quality of the carburetion equipment and equipment installation in general. Also, some of the fuels being examined have been vying for a position in the fuel market for longer than others and have performed more emissions testing, resulting in more emissions data being available. For instance, there is a great deal more information on the emissions from methanol fuelled vehicles than there is for the gaseous fuelled vehicles.

When considering the environmental implications of the alternative fuels being examined, emissions testing to date has indicated the following results when measured against gasoline and diesel fuels:

- **Greenhouse Gas Emissions**

Alternative transportation fuels produced from fossil fuel feedstocks such as coal, natural gas, and crude oil will not result in a significant reduction in greenhouse gas emissions, whereas renewable biomass resources (depending on how they are processed and used and

whether they are replenished) and improvements in vehicle efficiency may (see Table 6.1).

Methanol and natural gas fuelled vehicles produce less tailpipe CO_2 emissions than either gasoline or diesel fuel vehicles. The reason for this is that these fuels contain less carbon per unit of energy than do either gasoline or diesel fuel, are more efficient than gasoline and therefore provide greater travel distances per unit of energy. However, when compared to gasoline and diesel fuel over the entire fuel production and use cycle, the CO_2 advantage is diminished in the case of natural gas vehicles because of increased emissions of CH_4 and may be eliminated in the case of methanol which requires greater energy consumption at various stages throughout its life cycle.¹ Producing methanol from what would have been flared natural gas could provide an exception to this conclusion.

Producing alcohols such as ethanol or methanol from biomass, in particular woody biomass, can provide substantial reductions in greenhouse gases when compared to using gasoline or diesel fuel even though some greenhouse gases are emitted from the energy consumed and the fertilizer used in silviculture. However, using coal rather than natural gas as either the raw feedstock for methanol or the energy required for converting grain to ethanol would result in the production of as much or more greenhouse gases as the gasoline life cycle.²

- Ozone

Table 6.2 indicates the findings of a staff report by the California Air Resources Board (CARB).³ As these results indicate, natural gas, methanol and propane all have the potential to reduce ozone formation in the troposphere. Although the extent of the ozone reduction achievable from neat or near-neat ethanol fuelled vehicles is presently unknown due to the lack of available emissions data, the relative reactivities per mile of this fuel in comparison to methanol and gasoline suggests vehicles operating on E85 or E100 would also provide an ozone benefit.

The particulates being emitted into the atmosphere are major contributors to smog formation. Converting diesel engines to dual-fuel natural gas engines, without increasing power output, will lower the particulate emission levels. However, if the natural gas and diesel fuel control system incorrectly metres the fuel during accelerating transients, some over-fuelling may result in smoke.⁴

TABLE 6.1
EMISSIONS OF GREENHOUSE GASES

Fuel/Feedstock	CO ₂ -equivalent Emissions ^a percent change relative to petroleum
CNG, LNG, or methanol from biomass	~ -100
CNG from natural gas ^b	-16
Methanol from natural gas	-8
LNG from natural gas ^b	-7
Gasoline from crude oil	---
Methanol from coal	+69

SOURCE: Daniel Sperling, *New Transportation Fuels, A Strategic Approach to Technological Change* (Los Angeles, California and London, England: University of Calgary Press, Berkley), p. 326.

NOTE: The original source of the material illustrated in this table was Mark Deluchi, Robert Johnston, and Daniel Sperling, "Transportation Fuels and the Greenhouse Effect," *Transportation Research Record*, (forthcoming). A recent study by Mark Deluchi entitled, "Greenhouse Gas Emissions from LPG, Gasoline, Diesel Fuel, Methanol, CNG and Electric Vehicles," concluded that propane "will in most cases offer at least a 20 percent reduction in greenhouse gases compared to gasoline, and perhaps a small reduction compared to diesel fuel" (see Table A.8).

^aDoes not include N₂O emissions from motor vehicles. Emissions were calculated for production, distribution, and end-use activities.

^bIncludes CH₄ emissions adjusted to CO₂-equivalent basis.

TABLE 6.2

CARB 1989 STUDY RESULTS: RELATIVE OZONE AIR
QUALITY IMPACT OF VEHICLES POWERED BY
VARIOUS FUELS^a

Fuel Type ^b	Ozone Reactivity Factor ^c	
Gasoline	1.0	(baseline)
Methanol (M85)	0.05-0.56	(lower value reflects improved formaldehyde control)
LPG	0.67-0.85	(lower value for dedicated vehicle, higher value for dual-fuel vehicle)
CNG	0.36-0.45	(lower value for dedicated vehicle, higher value for dual-fuel vehicle)

SOURCE: California Energy Commission, *Fuels Report*, P300-89-018 (California: California Energy Commission, November 1989), p. 5-14.

^aDefinition of a Low-Emission Motor Vehicle in Compliance with the Mandates of Health and Safety Code Section 39037.05 (Assembly Bill 234, Leonard, 1987), CARB, Mobile Source Division, May 19, 1989.

^bOther fuel types tested were neat methanol (M100) and Ethanol (E85 and E95). The results for these fuels were set aside due to non-representative conditions encountered with the test vehicles.

^cThe "Ozone Reactivity Factor" provides a relative comparison of the ozone forming potential of equal amounts of emission products from each fuel type compared to gasoline. This factor, multiplied by the actual quality of emissions, would determine the extent of contribution to ozone formation.

Very low particulate emissions or smoke result from the combustion of alcohol in diesel engines. In optimized engines, NO_x emissions could be as much as 50 percent lower when operating on methanol.

- Carbon Monoxide

The leaner flammability limits of natural gas and propane indicate the potential to produce lower amounts of carbon monoxide emissions than gasoline. But, higher flame temperatures tend to result in nitrogen oxide emissions being greater.

Methanol and ethanol are also very lean burning, which could be due to their high heat of evaporation (creating an internal cooling effect) and lower flame temperature, resulting in lower CO emissions and NO_x than from gasoline. However, EPA testing at low temperatures, in both dedicated and flexible fuel vehicles, exhibited poorer CO performance when using methanol than gasoline vehicles. This same information is not readily available for E85 or E100 but the EPA suggests that under current control technology, NO_x and CO emissions can be the same as for gasoline.⁵

The conflict that appears consistent across all the fuels examined is that although it appears possible to configure engines for reduced CO and hydrocarbon emissions, the reduction is usually at the expense of increased NO_x levels. Conversely, adjusting the engines to reduce NO_x is at the expense of higher CO. The reason this dilemma exists is because CO and hydrocarbons are oxidized best in excess air in the engine and catalytic converter, whereas NO_x is reduced most effectively by a catalyst in oxygen-poor conditions.⁶

Carbon monoxide emissions are relatively low from diesel fuel engines. In comparison, diesel engines operating on alcohol at low loads may have increased CO emissions if the ignition quality is not adequate.⁷

Diesel engines, whether operating on natural gas in spark-ignition engines or on a combination of natural gas and diesel fuel, have low CO emissions. Even so, when compared to existing diesel fuel operations overall CO emissions may still be greater using natural gas.⁸

- Carcinogens

Both natural gas and propane are considered to be non-toxic fuels. Methanol, although highly toxic as is gasoline if ingested, is not considered to be a toxic

pollutant at levels of inhalation likely to occur from use as a motor vehicle fuel. However, both the U.S. Environment Protection Agency and the U.S. Health Effects Institute are continuing to conduct further research in this area.⁹ Ethanol is less toxic than methanol even though it also produces aldehydes. Acetaldehyde, the primary aldehyde emitted from ethanol fuelled vehicles, is known to be less carcinogenic than the formaldehyde or primary aldehyde emitted from methanol fuelled vehicles.

Alternative fuels must be capable of attaining competitive economics within the time frame determined by Canada's declining conventional oil reserves.

- On average nationally throughout 1989, natural gas benefited from a 25 cent per litre equivalent differential when compared to gasoline and a 15 cent per litre equivalent differential when compared to diesel fuel. With these price advantages, high mileage fleet vehicles (those travelling from 30 000 to 75 000 kilometres annually) such as taxis, delivery trucks and commuter buses can recover conversion costs and in some cases provide substantial savings over the life of the vehicles. Assuming a five-year life, personal automobiles travelling up to 20 000 kilometres per year would incur losses if the vehicle conversion costs were \$2,800 as suggested in the base case scenario. On the other hand, as the OEMs become involved and dedicated natural gas vehicles become available, incremental costs to the consumer will likely be as low as the differential cost between the natural gas cylinders being utilized and the gasoline tank which they replace. Even the personal-use vehicles become financially viable under this scenario.

The initial costs of a natural gas refuelling facility are high. Even the rental costs associated with a residential refuelling appliance, when added to the costs of conversion, make personal-use natural gas vehicles appear non-viable. But again, in the case of high mileage fleets, the savings attained through the price differential under most of the cases examined are capable of offsetting costs over the life of the vehicle.

- Propane is competitively viable when considered as a fuel for high mileage fleet vehicles. However, as with natural gas vehicles, the automobiles currently being converted to operate on propane are retrofits, not factory produced models, and therefore the costs incurred, although not as high as for natural gas, are difficult to recover over the life of a personal-use vehicle. Propane, unlike natural gas, is not

constrained by the need for development of a national refuelling infrastructure. Even when fleets maintain their own propane refuelling facilities, the capital costs incurred are about one-fifth those necessary for compressed natural gas.

- Methanol vehicle costs are, with large volume demand, less than the present costs of converting to propane or natural gas. In part, this reflects OEM interest and the manufacture of flexible fuel and/or dedicated alcohol vehicles in response to contracts in various parts of North America, particularly California, as well as in Brazil. A price differential as low as 9 cents per litre, which is achievable at prevailing methanol production costs, can make dedicated methanol or flexible fuel vehicles viable with optimum alcohol use. As with the other alternatives, however, when the costs of the refuelling stations are incorporated into the analysis the size of the fleet of vehicles being converted becomes a key variable in determining the overall cost to the individual consumer or fleet manager.
- The current economics of ethanol production in Canada make neat or near-neat fuel ethanol non-viable. But, as an oxygenate with a high octane rating, ethanol remains a candidate for increased growth in the Canadian transportation industry as a replacement for tetraethyl lead.

Alternative fuels must be capable of providing the necessary octane enhancement.

- Each of the alternatives examined in this study has a higher octane rating than gasoline (87-93) with natural gas excelling at 120-130 (see Table A.1).

Alternative fuels must be capable of being used as fuel substitutes and not only as fuel extenders.

- Natural gas, a clean burning, high octane, low cost fuel, has the potential to substitute for both gasoline and/or diesel fuel in the Canadian transportation sector once the necessary refuelling infrastructure is developed. In order to optimize on the attributes of natural gas and remove concerns regarding the increased environmental emissions which can result from improperly retrofitted dual-fuel vehicles, OEM designed mono-fuel vehicles will be necessary if extensive substitution is to occur.
- Due to its usually low relative cost and excellent operating characteristics, propane, the most widely used alternative fuel in Canada, has the potential for

continued substitution for gasoline. However, increased demand for its use as a substitute for gasoline and diesel fuel will require further technological developments to allow it to compare in performance and economy with natural gas and methanol.

- Methanol appears to be a viable substitute for diesel fuels as well as a competitive alternative for gasoline if used in a dedicated or flexible fuel vehicle.
- Ethanol is an alternative fuel source which, when blended with gasoline as a gasohol product or burned as an alternative to gasoline in flexible fuel vehicles, can enhance the octane value of the base fuel as well as extend our petroleum reserves.

Alternative fuels must have a plentiful supply source.

- Canada is rich in all three natural gas feedstocks: raw natural gas, coal and biomass. It is unlikely, therefore, that the viability of this fuel will be limited by supply constraints.
- Propane, a by-product of natural gas processing and a product of oil refining, can and has in the past incurred regional supply constraints as a direct result of high demands for propane in the heating market.
- Methanol from natural gas, coal or biomass would not be limited by supply constraints.
- As Canada is rich in biomass, strategically placed ethanol plants should not experience supply problems.

Alternative fuels must be easily distributable.

- Although natural gas for vehicle fuel use is the same gas which is supplied through the gas utility's pipeline distribution system for numerous commercial, industrial and residential uses, there are fewer than 120 natural gas service stations in Canada. The constraints on distribution result from the need for further compression of the fuel in order for it to be used in automobiles. Compression costs are very high and have restricted the use of NGV to niche markets such as fleet operations, which have access to sufficient quantities of natural gas and can justify the expense of a commercial compressor.
- In 1988, propane could be obtained at 5024 locations in Canada. The basic equipment and refuelling infrastructure necessary to provide consumers with

adequate conversion and service locations, as well as refuelling accessibility, is essentially in place. But, there remain refuelling equipment and procedural issues which still need to be addressed.

- Though methanol is not presently marketed at any fuelling stations in Canada, sufficient technical experience is available to address any problems with distributing methanol as an alcohol fuel.
- Ethanol is currently being marketed by Mohawk Oil Company Ltd. in a number of provinces across Canada in low level blends.

Alternative fuels must have widely developed and commercial production and vehicle technologies.

- The production technologies for producing natural gas, propane and methanol are well developed in Canada and large-scale production capacity is in place.
- There are well established technologies for both sugar and starch-based ethanol. However, further research and development is a must if the necessary economics are to be attained.
- Ethanol, when blended with gasoline in volumes of up to 10 percent, has been tested and found to maintain acceptable driveability characteristics in the vehicles available in the Canadian market-place. However, the physical characteristics of neat ethanol or methanol as well as propane and natural gas are such that modifications to both the current vehicle and engine designs as well as the fuel supply systems are required. Conversion kits are available from conversion manufacturers for both natural gas and propane. Flexible fuel vehicles, which will operate on alcohol/gasoline blends containing up to 85 percent ethanol or methanol, are also being tested in Canada. As well, methanol, natural gas, and propane engines are being designed and tested as contenders to replace diesel engines in large vehicles. Ethanol is also being tested in two buses as a replacement for diesel fuel.

The following synopsis indicates the transportation opportunities available to each of the fuels considered, based on the research and economic analysis undertaken for this study.

Natural Gas

Advantages:

- currently plentiful domestic supply;
- lowest priced alternative;
- infrastructure exists for shipping natural gas across Canada;
- home refuelling is possible;
- non-toxic;
- good safety record;
- due to its simple composition, maintains more complete combustion, therefore, lower exhaust emissions;
- highest octane rating, suggesting the potential for the highest compression ratios resulting in greater engine efficiency;
- enters the engine cylinder in its natural gaseous state, resulting in decreased spark-plug problems, smoother throttle response and easier cold weather starting;
- wider flammability limits than gasoline, giving more stable combustion and providing potential for greater energy efficiency and lower overall emissions; and
- current vehicle fleet can be converted to dual-fuel vehicles.

Disadvantages:

- lack of widespread refuelling facilities;
- refuelling somewhat more complicated than for gasoline;
- lower energy density combined with the weight of the cylinders results in a power reduction; and
- public concern with regard to safety (in spite of its good safety record).

Natural gas, one of Canada's most abundant natural resources, has a more secure long-term supply outlook than gasoline, diesel or propane. The low market price of this fuel as well as its clean burning characteristics suggest **this alternative fuel source has**

immediate potential for greater use in fleet operations. The current lack of widespread refuelling facilities and the cost of their construction, however, prevents rapid near-term expansion into the market for individual car owners. The advent of home refuelling facilities could reverse this disadvantage relatively quickly, provided that the capital and operating costs of these appliances can be significantly reduced.

Dual-fuel vehicles provide the operator with a choice of fuels, a benefit while the natural gas refuelling infrastructure is being constructed. However, neither fuel system operates at an optimum level, compromising the maximum efficiency and environmental gains achievable from a dedicated system. Further penetration of natural gas into the transportation sector, particularly on the basis of an efficient, clean burning fuel, will therefore require mono-vehicles designed to optimize the potential benefits attributed to natural gas.

Propane

Advantages:

- Canadian resource;
- second lowest priced alternative;
- infrastructure exists for shipping across Canada;
- non-toxic;
- safe to use - propane tanks are generally stronger and safer than gasoline tanks and less likely to explode in the case of a fire or accident because of relief valves through which built-up pressures are released;
- due to its simple composition, maintains more complete combustion than gasoline, thereby reducing exhaust emissions;
- higher octane rating than gasoline allowing for potentially higher compression ratios and greater engine efficiency;
- enters the engine cylinder in its natural gaseous state resulting in decreased spark-plug problems, smoother throttle response and easier cold weather starting; and
- current gasoline fleet can be easily converted to run on propane.

Disadvantages:

- limited supply;
- refuelling more involved than for gasoline;
- lower energy density in the liquid state, requiring more fuel than for gasoline on a liquid-volume basis for identical driving range;
- due to its higher vapour pressure, storage at moderate pressures is required to maintain a liquid state;
- as it is denser than air, will accumulate near the ground in poorly ventilated areas; and
- cold starting problems at very low temperatures.

Of the four alternative fuels examined, propane is currently the one most widely used in Canada. Due to its usually low relative cost and excellent operating characteristics, **propane will continue to be utilized in Canadian fleets.** Expansion of current propane markets will depend on technological developments which will allow it to compare favourably in performance and economy with its competitors in the fuel market.

Methanol

Advantages:

- Canadian resource - currently abundant supply of natural gas feedstock; even greater opportunities exist when utilizing remote natural gas;
- cheaper to produce than ethanol;
- refuelling facility requirements more compatible with those currently existing than for gaseous fuels;
- as a replacement for diesel fuel, will aid in controlling sulphur and particulate levels, thereby alleviating smog problems;
- emits less ozone pollutants than gasoline;
- higher octane rating than gasoline resulting in greater power;
- burns well at lean air-fuel ratios, yielding the potential for greater energy efficiency and lower overall emissions;

- OEMs have greater experience in designing vehicles to operate on liquid fuels such as methanol; and
- used in flexible fuel vehicles, will provide a solution to the chicken-and-egg problem.

Disadvantages:

- costs more to produce than gasoline;
- lower energy density requires more frequent refills or larger fuel tanks;
- material-compatibility problems in current vehicles due to its corrosive quality;
- may cause cold weather starting difficulties; and
- toxic.

Methanol is a relatively inexpensive, clean burning fuel when used as a substitute for gasoline in dedicated or flexible fuel vehicles or when used as a replacement for diesel fuels. This alcohol, which can be made from practically any organic material, may not only provide the power lost through lead phaseout but may prove beneficial in meeting future air quality standards.

The advantage of methanol's use in the flexible fuel vehicle is the allowance for wide usage in passenger cars while the refuelling infrastructure is being developed. Also, the addition of gasoline to the fuel would provide a solution to the flame luminosity concern as well as reduce the risk involved in storing methanol, which is theoretically ignitable at normal ambient temperatures. One concern in using M85 would be that in the case of a spill, the combined characteristics of methanol (which is miscible in water) and gasoline (which is not miscible in water) may result in greater disbursement of the fuels and less chance of containment.

The automobile manufacturers believe they will be able to achieve the formaldehyde emission requirements with methanol fuelled vehicles. Methanol, the other major tailpipe emission from combustion of this alcohol, is relatively non-reactive when compared to other hydrocarbon components in fossil fuels. Research is in progress to better determine the absolute effects of the levels of formaldehyde and methanol that would be emitted should methanol become a more widely used fuel in the vehicles present on our roadways.

Ethanol

Advantages:

- a renewable energy source when produced from biomass, a feedstock which is plentiful in Canada;
- burns well at lean air-fuel ratios, yielding the potential for greater energy efficiency and lower overall emissions;
- emits less ozone pollutants than gasoline;
- when added to gasoline, its high octane value provides an environmentally acceptable substitute for lead as an octane booster; and
- compatible with current vehicle fleet in blends up to 10 percent.

Disadvantages:

- most expensive of the alternatives to produce;
- has a lower energy density than gasoline and, therefore, will require either larger fuel tanks or more frequent refilling when used in flexible fuel vehicles; and
- may cause cold weather starting difficulties.

Ethanol-blended fuels can substitute for lead as an octane booster and provide refiners with the antiknock enhancement necessary for their gasoline products. However, ethanol production costs currently make this fuel non-viable in its neat or near-neat form in the absence of very large subsidies. Ongoing research may eventually provide the technological improvements necessary to enzymatically convert high yielding cellulose to ethanol economically. Should production economics become viable, this efficient burning alcohol fuel, which emits lower levels of reactive hydrocarbons than either gasoline or diesel fuel and burns without producing soot, could be used to fuel dedicated or flexible fuel vehicles and diesel powered urban buses.

6.3 The Current Barriers Confronting the Expansion of the Alternative Fuel Market

The factors which motivate governments to encourage the use of alternative fuel sources are not always those which influence

individual consumers. It is the issues of concern to consumers which initiate the demands of this nation's transportation sector. At least, that's the understanding in a competitive market-place. However, due to the magnitude of the risk and investments required to introduce an alternative fuel source to the market-place, government initiatives will be required. Why is this?

The answer is defined as the "**chicken-or-egg**" syndrome. Producers are leery of making the initial investments necessary for the manufacture of a new fuel if there is no assured market for their product. And automobile manufacturers are reluctant to risk large investments on the retooling and marketing costs required to produce a new vehicle unless consumer demand is sufficient to provide the necessary economies of scale to justify production; there is an assured supply of the required fuel as well as the necessary infrastructure for delivery and refuelling; and the fuel can be provided at a price acceptable to the consumer.

Another constraint obstructing the opportunities of alternative fuels is that of the **decision-making structure** involved with the introduction of a new fuel to the transportation market. Consumers require education in the advantages and disadvantages of each of the fuels under consideration. New fuel standards and safety regulations may need to be developed. Vehicle supply and the refuelling infrastructure must be assured. Each of these issues requires cooperative planning and decision making amongst all the stakeholders involved in fuel supply, vehicle manufacture, marketing and distribution. The diversity of the requirements confronting each of these participants suggests the need for leadership and/or mediation. In Canada, the institution best suited to provide this direction is the Federal Government. It must consider regional differences and requirements, provide direction and, if necessary, incentives to assure Canadians of access to alternative transportation fuels at reasonable prices, as well as a cleaner environment.

The transportation sector is an important link in the process of addressing Canada's concerns regarding environmental pollution. These solutions involve **costs**, not only the costs associated with producing low-emission vehicles versus conventional vehicles but the cost of producing the clean-burning fuels on which they operate. The fuel producers and distributors, the vehicle manufacturers and the retail station owners have one goal in common--profit. It is likely, therefore, that the additional costs which they incur from supplying

alternative fuel sources will be passed on to the consumer, and that these costs will in turn be influenced by the relative cost of crude oil, reformulated gasoline and diesel fuels.

Increasing crude oil costs will increase gasoline, diesel and propane prices more so than natural gas, methanol and ethanol prices. Also, the increased costs associated with reformulating gasoline will reduce the relative costs of clean burning alternative fuels.

Crude oil price shocks and tightening supplies promote interest in more stable priced fuels. The temporary increase in gasoline prices in response to the Iraq/Kuwait takeover will have varying effects on the alternative fuel prices. Natural gas is sold in large volumes and on a contract basis so it is unlikely that its price will respond in a major way to the increasing price of crude oil. Propane, on the other hand, is traded internationally in competition with gasoline and #2 fuel oil. It will therefore respond to any short-term price increases in either of these commodities by also increasing in price. As well, with 20 percent of the propane supply in Canada being a product of oil refining, as crude costs rise so also will propane costs and ultimately its price. Although methanol, like natural gas, should not have increasing prices reflective of the oil crisis, increased fuel costs to the farmer will eventually result in increased costs to the ethanol producers and rising ethanol prices. However, in balancing the desire for increased short-term profits against the potential for improved long-term market share, the former is often emphasized by marketers.

Based on the analysis undertaken for this study, Tables 6.3a through 6.5 present a summary of the price differentials required to make natural gas, propane and methanol viable in Canada's transportation sector. As fleet fuels, the lowest price differential required to recover the incremental costs associated with conversion and the refuelling infrastructure for natural gas and propane would be approximately 5 and 9 cents per litre equivalent, respectively. Personal vehicles would require a price differential of just over 13 cents a litre for both these fuels. These price differentials are net of available incentives. Methanol, without incentives, requires at least a 9 cent per litre equivalent differential for personal vehicles to recover these same costs and around 6 cents per litre equivalent for fleets.

The differentials in Tables 6.3b through 6.5 allow one to calculate the market price necessary to make each scenario presented viable in the current market-place (see also Figures 6.1 and 6.2). For

TABLE 6.3a

**NATURAL GAS PER-LITRE PRICE DIFFERENTIALS
REQUIRED FOR PAYBACK WITHIN VEHICLE'S LIFETIME**

Assumptions	Light/Medium Personal Vehicles	Light/Medium Fleet Vehicles	Heavy Vehicles	Heavy Vehicles	Buses
Assumed lifetime (yr)	5	5	7	7	16
Assumed Annual Distance (000s km)	20	75	40	70	50
Fuel Consumption (L/1000 km)	125	125	350	460	530

SOURCE: Canadian Energy Research Institute.

Scenarios used for the analysis shown in Table 6.3b, presented on the following page.

- Scenario 1: Light/medium vehicle, personal use, no compressor.
- Scenario 2: Light/medium vehicle, personal use, purchased home compressor.
- Scenario 3: Light/medium vehicle, five car fleet, two leased compressors at \$720 per year.
- Scenario 4: Light/medium vehicles, forty car fleet, commercial compressor at \$150,000 (less a 25 percent rebate) with \$2500 per year maintenance costs.
- Scenario 5: Heavy vehicle, vehicles weighing over 3855.6 kg.
- Scenario 6: Heavy vehicle, vehicles in the 47 000 kg gross weight range.
- Scenario 7: Bus.
- Scenario 8: Bus fleet of forty vehicles, with a commercial compressor as in (4), plus \$20,000 in cylinder replacement costs after eight years.
- Station Costs: \$250,000. Lifetime: fifteen years (If each station serves 190 vehicles [based on current NGV market stats], each consuming 2500 litre equivalent per year [based on 125 L/1000 km $\times$ 20 000 km], the station must receive 6.6 cents per litre equivalent in profit to recover the initial \$250,000 investment).

TABLE 6.3b
NATURAL GAS PRICE DIFFERENTIALS REQUIRED FOR
PAYBACK WITHIN VEHICLE'S LIFETIME

	L/M No Compressor	L/M + Home Compressor	L/M 5 Car Fleet + 2 Compressors	L/M 40 Car Fleet + Compressor	Heavy Vehicles ^a	Heavy Vehicles ^b	Buses	Bus Fleet + Compressor
Conversion Cost (\$ per vehicle)	2,200- 3,200	2,200- 3,200	2,200- 3,200	2,200- 3,200	3,200- 4,200	20,000- 25,000	20,000- 50,000	20,000- 50,000
Price Differential Required (\$/Le)	22.1-32.2	22.1-32.2	5.9-8.6	5.9-8.6	4.5-5.9	12.2-15.2	9.2-23.0	9.2-23.0
Conversion Incentives (Federal & Provincial) (\$)	1,500	1,500	1,500	1,500	1,500	---	---	---
Price Differential Equivalent (\$/Le)	-15.1	-15.1	-4.0	-4.0	-2.1	---	---	---
Compressor Cost (per vehicle, over lifetime, net of incentives)	---	1,500	1,145	3,061	---	---	---	3570
Price Differential Equivalent (\$/Le)	---	15.1	3.1	8.2	---	---	---	1.6
Station Costs (per vehicle, over lifetime of vehicle)	656	---	---	---	4,718	10,851	14,352	---
Price Differential Equivalent (\$/Le)	6.6	---	---	---	6.6	6.6	6.6	---
Net Price Differential Required (\$/Le)	13.6-23.7	22.1-32.2	5.0-7.7	10.1-12.8	9.0-10.4	18.8-21.8	15.8-29.6	10.8-24.6
OEM Conversion Cost (\$ per vehicle)	900	900	900	900	1,250	6,500	9,700	9,700
Price Differential Required (\$/Le)	9.1	9.1	2.4	2.4	1.7	4.0	4.5	4.5
Net Price Differential Required in OEM Case (no conversion incentives)	15.7	24.2	5.5	10.6	8.3	10.6	11.1	6.1

SOURCE: Canadian Energy Research Institute.

^aVehicles weighing > 3855.6 kg.

^bVehicles weighing > 47 000 kg.

TABLE 6.4

**PROPANE PER-LITRE PRICE DIFFERENTIALS
REQUIRED FOR PAYBACK WITHIN VEHICLE'S LIFETIME**

Assumptions	Light/Medium Personal Vehicles	Light/Medium Fleet Vehicles	Heavy Vehicles ^a	Heavy Vehicles ^b	Buses
Assumed lifetime (yr)	5	5	7	7	16
Assumed Annual Distance (000s km)	20	75	40	70	50
Fuel Consumption (L/1000 km)	125	125	350	460	530
Conversion Cost (\$ per vehicle)	1,400- 2,200	1,400- 2,200	1,800- 2,600	9,000- 15,000	10,000- 17,000
Price Differential Required (\$/L)	14.1-22.1	3.8-5.9	2.5-3.6	5.5-9.1	4.6-7.8
Incentives (provincial tax rebate) (\$)	750	750	750	750	750
Price Differential Equivalent (\$/L)	-7.5	-2.0	-1.0	-0.5	-0.3
Station Cost (\$)	666	2,497	4,789	11,016	14,589
Price Differential Equivalent (\$/L)	<u>6.7</u>	<u>6.7</u>	<u>6.7</u>	<u>6.7</u>	<u>6.7</u>
Net Price Differential Required (\$/L)	<u>13.3-21.3</u>	<u>8.5-10.6</u>	<u>8.2-9.3</u>	<u>11.7-15.3</u>	<u>11.0-14.2</u>
OEM Conversion Cost (\$)	600	600	750	3,900	4,400
Price Differential Required (\$/L)	<u>6.0</u>	<u>1.6</u>	<u>1.0</u>	<u>2.4</u>	<u>2.1</u>
Net Price Differential Required in OEM Case (no conversion incentives)	<u>12.7</u>	<u>8.3</u>	<u>7.7</u>	<u>9.1</u>	<u>8.8</u>

SOURCE: Canadian Energy Research Institute.

STATION COSTS: \$40,000. Thirty vehicles per station each consuming 2500 litres equivalent per year, with a fifteen year station life. This requires a 6.74 cents per litre equivalent profit to recover the start-up cost of \$40,000.

NOTE: The infrastructure for propane is essentially in place and the station costs incurred to date have likely already been recovered. The net price differential indicated as necessary could therefore be 6.7 cents per litre equivalent lower. Also, the \$750 incentive is only available in Ontario.

^aVehicles weighing > 3855.6 kg.

^bVehicles weighing > 47 000 kg.

TABLE 6.5

**METHANOL PER-LITRE PRICE DIFFERENTIALS
REQUIRED FOR PAYBACK WITHIN VEHICLE'S LIFETIME**

Assumptions	Light/Medium Personal Vehicles	Light/Medium Fleet Vehicles	Heavy Vehicles ^a	Heavy Vehicles ^b	Buses
Assumed lifetime (yr)	5	5	7	7	16
Assumed Annual Distance (000s km)	20	75	40	70	50
Fuel Consumption (L/1000 km)	125	125	350	460	530
Conversion Cost (\$ per vehicle)	500- 2,000	500- 2,000	2,200- 3,200	6,000- 12,000	12,000- 28,000
Price Differential Required (\$/L)	5.0-20.0	1.3-5.4	3.1-4.5	3.7-7.3	5.5-12.9
Station Cost (\$)	358	1341	2573	5919	7828
Price Differential Equivalent (\$/L)	<u>4.0</u>	<u>4.0</u>	<u>4.0</u>	<u>4.0</u>	<u>4.0</u>
Net Price Differential Required (\$/L)	<u>9.0-24.0</u>	<u>5.3-9.4</u>	<u>7.1-8.5</u>	<u>7.7-11.3</u>	<u>9.6-16.9</u>
OEM Conversion Cost (\$)	300	300	1050	5,600	6,600
Price Differential Required (\$/L)	<u>3.0</u>	<u>0.8</u>	<u>1.5</u>	<u>3.4</u>	<u>3.0</u>
Net Price Differential Required in OEM Case (no conversion incentives)	<u>7.0</u>	<u>4.8</u>	<u>5.5</u>	<u>7.4</u>	<u>7.0</u>

SOURCE: Canadian Energy Research Institute.

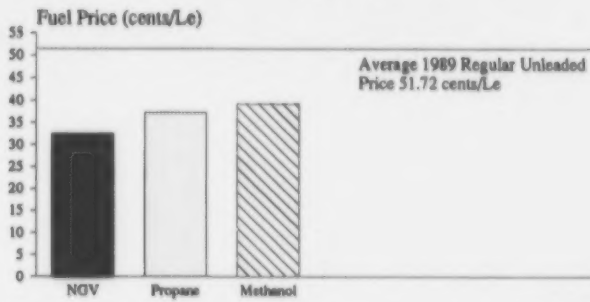
STATION COSTS: \$150,000. Assumes each station serves 190 vehicles, each consuming 2500 litre equivalent per year. If existing stations added methanol, costs as low as \$40,000 may be required for upgrading stations suggesting a 1 cents per litre equivalent differential required to recover station costs rather than 4 cents per litre equivalent.

NOTE: In discussions with the OEMs, it has been suggested that large volume demand is necessary to sell the flexible fuel vehicles at costs as low as those indicated in the above chart (particularly the OEM conversion cost) otherwise, costs will never be recaptured. In actual fact, the current cost of producing the flexible fuel vehicles being sold for demonstration purposes are many thousands of dollars more than indicated. However, these costs are presently being absorbed either by the groups involved with the projects or by the OEMs themselves who are also trying to determine what the market potential for these vehicles actually is.

^aVehicles weighing > 3855.6 kg.

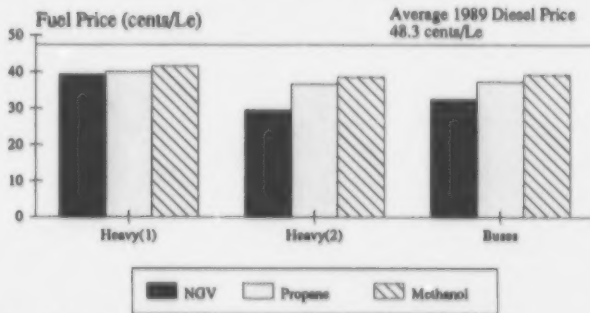
^bVehicles weighing = 47 000 kg.

Figure 6.1
Prices at Which Conversions
Are Viable - L/M Vehicles



SOURCE: CERL.

Figure 6.2
Prices at Which Conversions
Are Viable - Heavy Vehicles



SOURCE: CERL.

- (1) Heavy Vehicles > 3855.6 kg.
(2) Heavy vehicles approx. 47000 kg.

example, converting a bus to operate on natural gas, propane or methanol would require a market price per litre equivalent of each of the fuels to be no greater than as follows:

	<u>Natural Gas</u>	<u>Propane</u>	<u>Methanol</u>
Diesel Fuel Price	52.8	52.8	52.8
Price Differential Required	<u>15.8-29.6</u>	<u>11.0-14.2</u>	<u>9.6-16.9</u>
Market Price (¢/Le)	37.0-23.2	41.8-38.6	43.2-35.9

OEM Case

Price Differential Required	<u>11.1</u>	<u>8.8</u>	<u>7.0</u>
Market Price (¢/Le)	41.7	44.0	45.8

Historically, volatile oil prices and accompanying fluctuations in gasoline and diesel prices have resulted in consumer uncertainty and enhanced interest in fuels with greater price stability. This suggests that holding these alternative price differentials constant rather than allowing them to swing with gasoline and diesel prices would provide a stability which may in turn result in increased market share for these alternatives. Although short-term broadening of these differentials would at times provide increased "short-term" savings to the consumer, stability in an uncertain market-place is more apt to persuade the consumer to convert.

It is difficult to determine the actual cost of converting 10 percent of the conventional fuel market to the alternative fuels examined in this study. The jobs, investments and spinoffs through a secondary industry created would obviously be offset by job losses etc. in the conventional fuel market. However, using the regional forecast analysis in Appendix I to determine the number of new stations and conversions that would take place between 1990 and 2000 suggests the following discounted incremental costs:

Cost of Converting to Alternative Fuels

	<u>Le Required By Year 2000 (10⁶)</u>	<u>Number of Stations (net of existing)</u>	<u>Number of Conversions (net of existing)</u>	<u>NPV Total Costs (\$10⁶)</u>
Natural Gas	1,732	3530	667,893	1967
Propane	1,443	477	437,150	702
Methanol	1,626	3423	650,279	780
Total				3449

Regional demands and differences will also require consideration when promoting the use of any alternative on the basis of either economic diversification or environmental concerns.

6.4 Conditions for the Commercialization of Alternative Fuels

Condition 1. Assurance of commitment from the Federal and Provincial Governments towards alternative fuels is necessary for these fuels to advance or gain entrance into an already mature and established market.

Condition 2. More extensive investment is necessary in terms of research, development and, where necessary, demonstration, particularly in the following areas:

- (i) optimization of public fuelling station designs and residential refuelling appliances;
- (ii) methods to control nitrogen oxide emissions;
- (iii) means of lowering incremental vehicle conversion costs;
- (iv) designing mono-fuel vehicles for gaseous fuels;
- (v) a generic electronic control system for gaseous fuels;
- (vi) the safety issues of concern for the alcohol fuels, in particular that of flame luminosity and the flammability of the vapour in the fuel tank;
- (viii) continued research into clean coal technologies for the conversion of coal to methanol; and
- (ix) ethanol production technologies which will provide a cost-effective method of converting cellulose to ethanol.

Condition 3. Viable market penetration rates, through extensive marketing research both domestically and internationally, must be determined and targetted for each of the alternatives.

Condition 4. Federal energy policies regarding the transportation industry must consider the long-term environmental effects associated with the use of all vehicle fuels.

Condition 5. Cooperative decision-making amongst all the alternative transportation fuel stakeholders is required for successful market expansion of the alternatives.

Condition 6. Reliable raw material supplies and a distribution system must be assured in order for alternative fuels to gain a greater share of Canada's transportation fuel market.

Condition 7. Alternative fuel price differentials relative to gasoline and diesel must be stable, competitive, and large enough to allow the consumer to recover his investment costs. Prices must be tied to the transportation fuel market and not to the heating or grain market.

Condition 8. A significant portion of government fleets, including buses, should gradually be converted to methanol, natural gas and/or propane to test the viability of these fuels for Canadian automobiles. Fuel efficiency and emissions data must be collected, analysed and made publicly available.

Condition 9. Public awareness must be encouraged and mechanics, refuelling attendants and operators must be informed as to the characteristics of each of the alternatives being considered.

Condition 10. Though the regulation of gasoline quality is a provincial obligation, product integrity must be assured through national standardization and regulations in order to ensure satisfaction of the customer's real or perceived performance requirements and competitive equity among the stakeholders, particularly the refiners. The Federal Government must be the arbitrator who defines fuel and fuel using equipment qualifications as well as product distribution and dispensing.

Condition 11. Economic incentives, where deemed necessary, should be designed and promoted in a fashion which assures the consumer of government support for the fuel but with the understanding that they will only be provided until market forces can take over and the alternative fuels hold their own in the transportation sector. **While incentives may be the catalyst necessary to get the industry started, they must not become the basis upon which long-term economic viability is determined.**

Condition 12. The Federal government must provide the support necessary to remove any institutional and attitudinal barriers

preventing the development of the necessary technology, infrastructure and standards required for the introduction of any one of these alternative fuels. This will allow the competitive market-place to dictate whether natural gas, propane, methanol and/or ethanol can efficiently and effectively contribute to the requirements of the Canadian transportation industry.

6.5 Conclusions

Canada will continue to experience increasing demand for economically viable, clean burning transportation fuels. Although gasoline and diesel fuel will maintain leading positions in the transportation fuel industry through the coming decades, alternative fuels can play a significant role in Canada's transportation sector.

The transportation sector is almost totally dependent upon crude oil for its fuel supplies and consumes roughly 17 percent¹⁰ of Canada's primary energy sources. The nation's conventional crude reserves are declining. Canada is currently importing 542 thousand barrels of crude oil a day.¹¹ As well, there is an ongoing political crisis in the Middle East, which contains the largest supplies of conventional oil in the world. Political instability in any of the OPEC or non-OPEC nations imposes potential supply constraints and crude price fluctuations, which have direct implications for any economy relying on imported petroleum products. **Stability of crude oil, product markets and prices is a concern confronting Canadians.**

The automobile provides the personal freedom of mobility demanded by our democratic society. And yet, cars are a major source of the anthropogenic pollutants in Canada and the rest of the world. The quality of our atmosphere determines the quality of our lives. **The environment is a source of concern for Canadians.**

Alternative fuels such as natural gas, propane, methanol and ethanol can and will help Canadians meet existing and future transportation requirements. The size of their role will be dependent on research and development efforts, as well as on the public awareness of these alternatives and their potential as clean burning fuels.

The switch to alternative fuels will take time. The costs will be high. Canadians must be willing to take risks in the near term in order to achieve the long-term potential gains of secure transportation fuels and a cleaner environment.

Footnotes

¹Mark A. DeLuchi, *Emissions of Greenhouse Gases from the Use of Gasoline, Methanol, and Other Alternative Transportation Fuels* (Davis, California: University of California, Division of Environmental Studies and Transportation Research Group, December 1989), pp. 7 and 8.

²*Ibid.*, p. 12.

³California Energy Commission, *Fuels Report*, P300-89-018 (California: California Energy Commission, November 1989), pp. 5-13.

⁴International Energy Agency, *Substitute Fuels for Road Transport, A Technology Assessment* (Paris, France: Organization for Economic Co-operation and Development/International Energy Agency, 1990), p. 63.

⁵United States Environmental Protection Agency, *Analysis of the Economic and Environmental Effects of Ethanol as an Automotive Fuel, Special Report* (Ann Arbor, Michigan: Office of Mobile Sources, April 1990), p. 44.

⁶International Energy Agency, *Substitute Fuels for Road Transport, A Technology Assessment* (Paris, France: Organization for Economic Co-operation and Development/International Energy Agency, 1990), p. 67.

⁷*Ibid.*, p. 72.

⁸*Ibid.*, p. 63.

⁹United States Environmental Protection Agency, *Analysis of the Economic and Environmental Effects of Methanol as an Automotive Fuel, Special Report* (Ann Arbor, Michigan: Office of Mobile Sources, September 1989), p. 60.

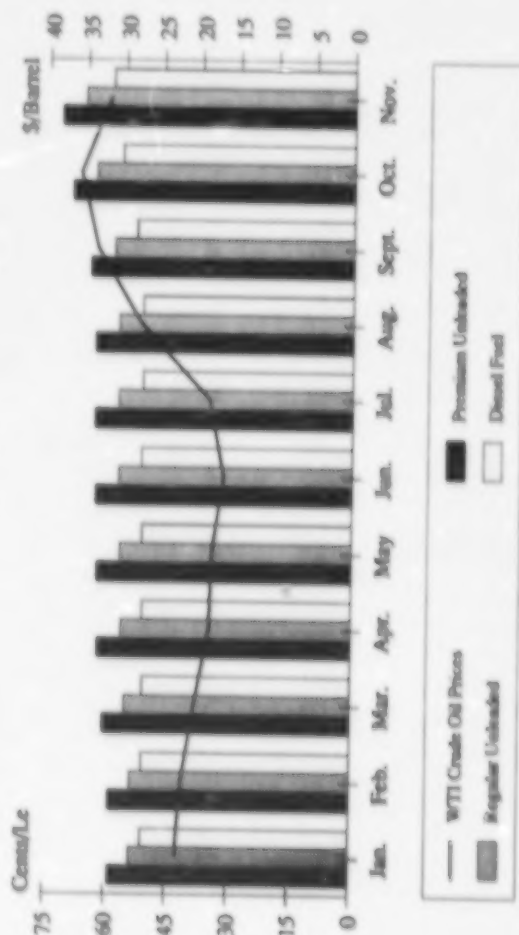
¹⁰Energy, Mines and Resources Canada, *Energy Statistics Handbook*, pp. 2.1, 2.3A.

¹¹*Energy Trends, Canadian Energy Trends Quarterly*, Vol. 8, No. 1 (Markham, Ontario: Canadian Enerdata Ltd., May 1990), p. 11.

Appendix A
**CHARACTERISTICS OF THE
ALTERNATIVE FUELS**

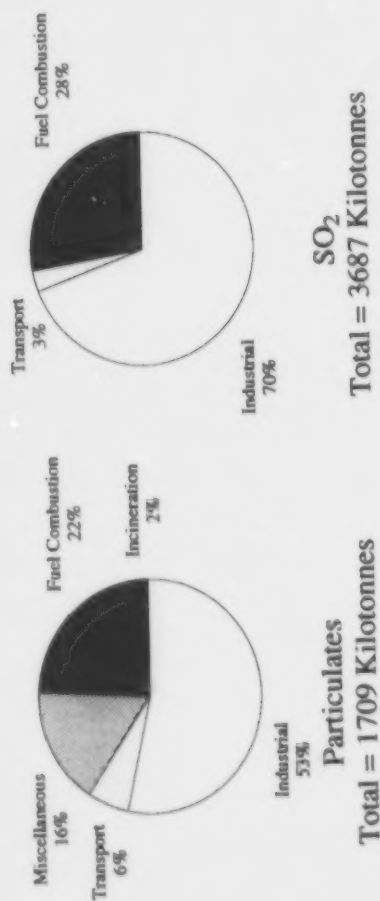


Figure A.1
Retail Fuel Prices Versus WTI
(1990)



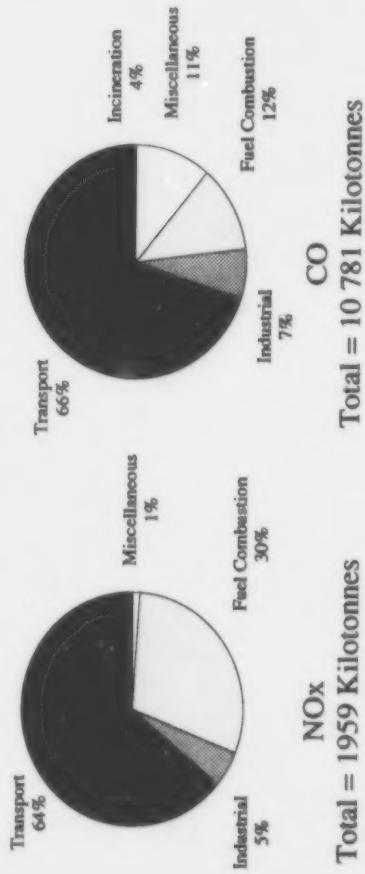
SOURCES: Globe and Mail, Energy, Mines and Resources Canada.

Figure A.2
Total Canadian Emissions by Source
Category for Particulates and SO₂, 1985



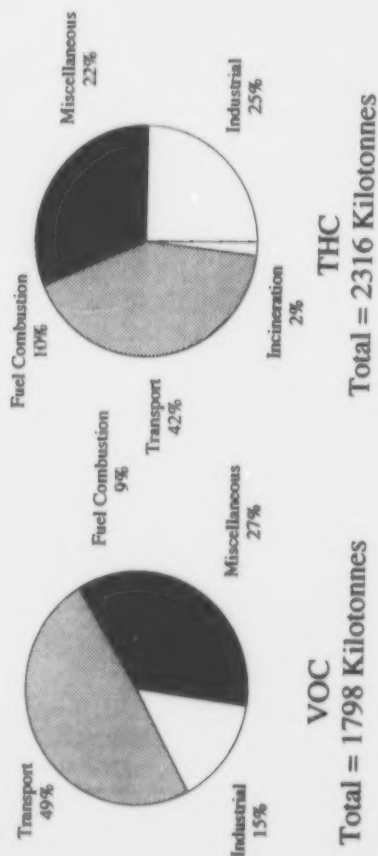
SOURCE: The 1985 Canadian Emissions
Inventory of Common Air Contaminants,
Draft Report.

Figure A.3
Total Canadian Emissions by Source
Category for NOx and CO, 1985



SOURCE: The 1985 Canadian Emissions
Inventory of Common Air Contaminants,
Draft Report.

Figure A.4
Total Canadian Emissions by Source
Category for VOC and THC, 1985



SOURCE: The 1985 Canadian Emissions
Inventory of Common Air Contaminants,
Draft Report.

TABLE A.1
COMPARATIVE PROPERTIES OF GASOLINE AND DIESEL WITH
NATURAL GAS, PROPANE, METHANOL AND ETHANOL

Properties	Gasoline	Diesel	Natural Gas	Propane	Methanol	Ethanol
Physical Properties						
Specific Gravity (liquid at 0°C)	0.72-0.78	0.79-0.88 ^a	0.13 ^b	0.51	0.796	0.789
Vapour Pressure (kPa @ 20°C)	27.6-55.1	0.0005 atm @ 37.8°C	N/A	Tank Pressure	13.1	5.5
Liquid Energy Density (Btu/L)	32842	36653	19910	24127	14941	19990
Gas Energy Density (Btu/L)	N/A	N/A	5353	---	N/A	N/A
Chemical Properties						
Formula		^d	CH ₄ (methane)	C ₃ H ₈ ^c	CH ₃ OH	C ₂ H ₅ OH
Molecular Weight	^c 120 (approx.)	---	16.04	44 ^e	32.0	46.1
Percentage Carbon	85-98	---	75	82 ^e	37.5	52.1
Percentage Hydrogen	12-15	---	25	18 ^e	12.6	13.1
Percentage Oxygen	0	---	N/A	N/A	49.9	34.7
Stoichiometric Air/Fuel Ratio (by weight)	14.2-15.1	14.5-15.1	17.3	15.6	6.4	9.0

(Continued on Next Page)

TABLE A.1 (Continued)

Properties	Gasoline	Diesel	Natural Gas	Propane	Methanol	Ethanol
Thermal Properties						
Heat of Vaporization (kJ/kg)	310	285	520	457.6	1100	904
Octane Ratings						
Research Motor (R+M)/2	90-100 80-90 85-95	N/A N/A	130 125-130 127.5-130	107 94 100.5	106 92 99	106 91 98.5
Cetane Rating	16-19	38-51	0	---	---	---
Flammability Limits (percent by volume in air)	1.0-8.0	0.7-5.0	5.0-15.0	2.1-9.3	6.7-36	4.3-19
Heat of Combustion (MJ/kg)	43.5	45.3	50.0	46.3	19.6	26.9
Flash Point (°C)	-45	43-88	-157	-104	11	21
Auto-Ignition (°C)	232-482	204-260	540	470	464-470	420

SOURCES: Ontario Energy, U.S. Department of Energy, U.S. Environmental Protection Agency, Bio-joule, and CERL.

^aAt 60°F with respect to water at 60°F.

^bAt 80°F with respect to water at 60°F.

^cMixture of hydrocarbons, typically C₄-C₁₀.

^dMixture of hydrocarbons, typically C₁₂-C₂₀ compounds.

^eAccurate for pure propane and approximate for automotive-grade propane, which may contain up to 10 percent of other compounds.

TABLE A.2
CANADIAN ANTHROPOGENIC EMISSION
INVENTORY
(tonnes X 10⁶)

	Hydrocarbons	Carbon Monoxide	Carbon Dioxide	Nitrogen Oxides	Particulate Matter
Light-Duty Vehicles ^a	575	4 694	63 197	464	
Heavy-Duty Vehicles ^b	146	1 127	33 490	334	23
Other Transportation	48	250	21 175	188	6
Other Anthropogenic	971	4 737	271 363	954	---
TOTAL	1 740	10 808	389 225	1 941	N/A

SOURCE: Energy Mines and Resources Canada.

^aLight-duty vehicles includes motorcycles, passenger cars, and trucks 3855 kg GVWR and less.

^bHeavy-duty vehicles includes trucks over 3855 kg GVWR.

TABLE A.3
PETROLEUM REFINING

<u>Product Yield Based Upon One Barrel of Feed</u>						
Gasoline					0.625 bbl	
Middle Distillates (diesel)					0.207 bbl	
Fuel Oil					0.105 bbl	
Coke					0.875 lbs	
Light Ends					9.02 lbs	
<u>Atmospheric Emissions, Gasoline Refinery (lb/day)^{a,b}</u>						
	Part.	SO _x	CO	HC	NO _x	CO ₂
Crude Distill.	3 080	6 400	533	533	5 330	N/A ^c
Mid-Distill.	45	64	38	65.4	518	"
St run Naphtha	18	26	15	25.7	207	"
Heavy Naphtha	1 660	3 560	287	288	2 870	"
Gas oil hydro.	326	703	57	56	567	"
FCCU	124	176	106	181	1 425	"
CO boiler	491	3 020	256	160	6 370	"
Hydrocracker	131	185	110	1 077	1 110	"
Heavy Hydro. Crack	1 650	3 540	285	286	2 854	"
Propane Deasphalt.	622	884	48	81	656	"
Hydrogen Plant	1 720	345	344	338	6 890	"
Miscellaneous	513	3 847	191	73 709	1 193	"
Total	10 380	22 750	2 270	76 800	29 990	N/A
<u>Gasoline Refinery Emissions^d</u>						
	0.0045	0.098	0.0010	0.0333	0.01300	512.4

SOURCE: Energy, Mines and Resources Canada, *Cost-Effectiveness of Alternative Transportation Fuels in Urban Buses* (Ottawa, Ontario: CANMET, November 1989), pp. 61, 64 and 65.

^aSources - Noyes Data Corporation.

^bBasis: 200,000 bbl/day Crude Feed (input).

^cN/A = not available.

^dIn grams of airborne emissions per litre of petroleum (gasoline or diesel) produced.

TABLE A.4

AIR POLLUTANT EMISSIONS FROM ENERGY
CONVERSION PROCESSES WITH CONTROLS
(grams per million Btu of output)

Conversion Process	Feedstock	Particulates	SO _x	HC (organic compounds)	NO _x	CO	CO ₂
Pyrolysis (surface retort)	Oil shale	10-35	3-16	3-15	50-150	3-16	55,000
Direct Liquefaction ^a	Bituminous coal, 4% sulphur	10-25	18-60	0.3-3	4-210	3-5	50,000
Methanol (thermochemical conversion: gasification) ^b	Subbituminous and lignite coal 0.4-0.6% sulphur	1-25	30-200	100-500 ^c	15-150 ^c	NA	65,000-90,000
Great Plains SNG Plant ^d	Lignite coal	11	106 ^e	no limit ^d	63	no limit ^d	no limit ^d
Methanol (thermochemical conversion: gasification)	Wood	0-30 ^c	negl.	NA	10-200 ^c	NA	NA
Ethanol (biocconversion: fermentation)	Corn	45-370	37-1500	5-140	100-830	10-170	38,800-47,400

(continued on next page)

TABLE A.4 (continued)

Conversion Process	Feedstock	Particulates	SO _x	HC (organic compounds)	NO _x	CO	CO ₂
Ethanol (acid cellulose hydrolysis)	Wheat straw and corn residue	100-200	800-1100	NA	500-600	NA	NA
Electricity-generating coal-fired plant ^a	Bituminous coal, 2% sulphur	20	200-1000	very low	very low	100-500	NA
Petroleum refinery ^d	Crude oil	2	11	10	9	NA	NA

SOURCE: Daniel Sperling, *New Transportation Fuels, A Strategic Approach to Technological Change* (Los Angeles, California and London, England: University of California Press, Berkeley), pp. 316, 317.

NA: Not Available.

^aBased on Exxon Donor Solvent and Solvent Refined Coal II processes.

^bBased on various gasifier technologies. The upper values refer to low-temperature Lurgi gasifiers.

^cThe upper value is highly suspect.

^dEmission rates for this plant are those established in the plant's air quality permit. All emissions limits were met except those for SO_x.

^eBased on new source performance standards (NSPS) for new powerplants.

^fBased on California data for 1981 provided by Air Resources Board; emission rates are somewhat higher elsewhere in U.S.

^gActual SO_x emissions in 1986 were 360 grams per million Btu.

TABLE A.5
PROJECTED IN-USE GASOLINE VOC-EQUIVALENT
EMISSIONS FOR GASOLINE, METHANOL
AND CNG VEHICLES
(grams per mile)

	NMHC	NMHC Reactivity Factor	Methanol	Methanol Reactivity Factor	HCHO	Formaldehyde Reactivity Factor	Gasoline VOC- Equivalent
Gasoline:							
- Current Standards	(1.73	x 1.00)	+	x (0.0	+	x (0.007	= 1.75
- Proposed Standards	(0.94	x 1.00)	+	x (0.0	+	x (0.005	= 0.95
FFV in MS:							
- Readily Feasible	(0.35	x 1.00)	+	x (0.95	+	x (0.06	= 0.66
- Optimized	(0.31	x 1.00)	+	x (0.75	+	x (0.035	= 0.53
M100:							
- Optimized	(0.05	x 1.00)	+	x (0.572	+	x (0.015	= 0.19
Dual-Fuel CNG:							
- Worst Case	(0.604	x 1.00)	+	x (0.0	+	x (0.004	= 0.61
- Best Case	(0.489	x 1.00)	+	x (0.0	+	x (0.004	= 0.5
Dedicated CNG:							
- Worst Case	(0.186	x 1.00)	+	x (0.0	+	x (0.004	= 0.19
- Best Case	(0.057	x 1.00)	+	x (0.0	+	x (0.005	= 0.07

SOURCE: Environmental Protection Agency, *Analysis of the Economic and Environmental Effects of Compressed Natural Gas as a Vehicle Fuel, Volume 1, Passenger Cars and Light Trucks* (Ann Arbor, Michigan: Office of Mobile Sources, April 1990), p. 27.

All fuels except dedicated CNG have hot soak/diurnal, running losses, and refueling losses included in addition to exhaust NMHC emissions. Hot soak/diurnal, running losses, and refueling losses for dual-fuel CNG vehicles are assumed to be nearly equal to those of gasoline-fueled vehicles corresponding to the standards proposed by the President. These values of 0.18 grams per mile for hot soak/diurnal, 0.16 grams per mile for running losses, and 0.07 grams per mile for refueling were used as 0.18, 0.16 and 0.03 for dual-fuel CNG. The reduction in refueling losses reflects less fueling with gasoline.

TABLE A.6
LIFETIME AVERAGE VEHICLE TAILPIPE
EMISSIONS DATA
(grams per mile)

	Gasoline	Diesel	LD-MeOH	HD-MeOH	LD-NG	HD-NG	LD-EtOH	HD-EtOH
CH ₄	0.10	0.10	0.07	0.05	1.40	3.00	0.07	0.05
N ₂ O	0.07	0.06	0.07	0.06	0.07	0.06	0.07	0.06
CO ₂ from engine oil	2.00	4.00	2.00	4.00	1.00	2.00	2.00	4.00
CO ₂ from fuel	264.07	1963.93	213.52	1945.20	169.51	1630.86	0.00	0.00
Total CO ₂ plus CO ₂ - Equivalent of CH ₄ , N ₂ O	260.01	1963.59	229.12	1968.28	218.73	1679.36	14.11	15.79

SOURCE: Mark A. DeLuchi, *Emissions of Greenhouse Gases From the Use of Gasoline, Methanol, and Other Alternative Transportation Fuels* (Davis, California: University of California, Division of Environmental Studies and Transportation Research Group, December 1989), p. 19.

NOTE: LD = light-duty application; HD = heavy-duty application; MeOH = methanol; and EtOH = ethanol.

TABLE A.7
G/MILE OF CO₂ EQUIVALENT-EMISSIONS, ENTIRE FUEL
PRODUCTION AND USE CHAIN, BASE CASE

grams per mile	Gasoline	Diesel	LD-MeOH	HD-MeOH	LD-NG	HD-NG	LD-EtOH	HD-EtOH
Vehicles	280.0	1983.6	229.1	1968.3	218.7	1679.4		
With Biofuels	0.0	0.0	14.4	17.4	24.8	39.1		
Compress/Liquefy	0.0	0.0	0.0	0.0	46.1	391.8	14.1	15.8
With Biofuels	0.0	0.0	0.0	0.0	39.7	337.1	0.0	0.0
Fuel Distribution	3.2	23.2	10.7	120.2	0.0	0.0		
With Biofuels	0.0	0.0	2.7	23.2	0.0	0.3	8.3	72.6
Fuel Production	25.3	190.8	52.2	559.1	0.0	0.0		
With Biofuels	0.0	0.0	23.6	215.3	3.8	32.2	245.2	2145.8
Feedstock Trans.	3.8	27.3	0.0	0.0	8.1 ^a	69.2 ^a		
With Biofuels	0.0	0.0	4.5	43.4	5.3	45.2	4.8	42.3
Feedstock Recovery	12.0	86.0	37.8 ^b	424.2 ^b	15.8	134.5		
With Biofuels	0.0	0.0	22.8	241.4	29.3	248.6	100.4	878.7
CH ₄ Leaks/Flares	8.0	58.0	0.0	0.0	12.0	246.0		
With Biofuels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Grand Total, Gm/mile	335	2388	335	3131	293	2424	373	3155
With Biofuels	--	--	67	516	92	637		
Percent Changes	--	--	-0	30	-9	7		
With Biofuels	--	--	-80	-77	-69	-70	12	34

SOURCE: Mark A. DeLuchi, *Emissions of Greenhouse Gases From the Use of Gasoline, Methanol, and Other Alternative Transportation Fuels* (Davis, California: University of California, Division of Environmental Studies and Transportation Research Group, December 1989), p. 22.

NOTE: In all cases "with biofuels" shows the results if biomass is used as the feedstock rather than a fossil fuel. NG-biofuels case assumes that all NG, including any used at power plants, is made from biomass. CO₂ emissions from the combustion of biofuels are not counted here, because they are not net emissions to the atmosphere (the carbon in the fuel came originally from the atmosphere). Thus, the biofuel cycle produces less greenhouse gas emissions wherever biomass replaces fossil fuel as the energy source. Methanol case shown is methanol from remote natural gas.

^aIncludes all pipeline transportation of NG. For bio-NG, pipeline transmission is under fuel distribution. Pipeline compressors burn bio-NG.

^bIncludes emissions from natural gas recovery and transmission. CH₄ loads are included here.

TABLE A.8
G/MILE CO₂ EQUIVALENTS, ENTIRE FUEL-PRODUCTION AND
USE-CYCLE, WITH AND WITHOUT MATERIALS, BASE CASE

	Gasoline		Diesel		M65		M100		Dual-Fuel CNG		LPG/CNG	
	LDV _s	HDV _s	LDV _s	HDV _s	LDV _s	HDV _s	LDV _s	HDV _s	LDV _s	HDV _s	LDV _s	HDV _s
Vehicles	350.9	1950.5	295.5	1921.4	288.9	1788.1	281.7	1942.6				
Compression	0.0	0.0	0.0	0.0	50.7	347.3	0.0	0.0				
Fuel Distribution	1.4	8.8	3.1	26.3	11.6	79.6	1.7	12.3				
Fuel Production	58.5	172.7	66.1	502.5	7.5	51.1	8.1	58.7				
Feedstock Transportation	3.5	21.1	6.4	53.1	0.0	0.0	0.0	0.0				
Feedstock & Fertilizer	12.3	76.0	23.5	197.1	14.0	95.5	10.7	77.5				
CH ₄ Leaks & Flares	5.2	31.9	10.1	85.2	16.5	112.6	5.1	41.1				
First Total	431.8	2260.9	404.7	2785.5	389.1	2474.2	307.9	2132.2				
Percent Changes	--	--	-6	23	-10	9	-29	-6				
g/mile Car Assembly	14.3	46.1	14.3	46.1	14.8	49.0	14.6	46.6				
g/mile Materials	50.1	161.7	50.1	161.7	54.8	189.4	51.0	163.2				
Second Total ^a	496.3	2468.6	469.1	2993.2	458.7	2712.5	373.5	2342.0				
Percent Changes	--	--	-5	21	-6	10	-25	-5				
LDV + HDV Total ^b	594.9		595.3		571.3		472.0					
Percent Changes			0		-4		-21					

SOURCE: Mark A. DeLuchi, "Greenhouse Gas Emissions from LPG, Gasoline, Diesel Fuel, Methanol, CNG, and Electric Vehicles," prepared for R.F. Webb Corporation Ltd. (Ottawa, Ontario, October 4, 1990), p. 23.

NOTE: HD = Heavy-duty application (diesel); LD = Light-duty application (gasoline).

^aSecond total is equal to the first total plus Gm/mile from assembly and materials manufacture.

^bGm/mile emissions from LDV_s, weighted by LDV VMT share, plus Gm/mile emissions from HDV_s, weighted by HDV VMT share.

Appendix B

**CURRENT AND PROPOSED REGULATIONS AND
EMISSIONS REQUIREMENTS IN THE
CANADIAN VEHICLE FLEET**



Appendix B

CURRENT AND PROPOSED REGULATIONS AND EMISSIONS REQUIREMENTS IN THE CANADIAN VEHICLE FLEET

B.1 CGSB Standards for Transportation Fuels

The regulation of transportation fuel quality in Canada is a provincial obligation. Not all the provinces have formal specifications for gasoline and similar type vehicle fuels. Ontario, Nova Scotia and Prince Edward Island require that all gasoline sold within their province meet CGSB standards. Quebec and Alberta have individual but similar standards.

If the alternative fuels being examined in this study are to continue to vie for a larger share of the transportation fuel market, then it will be necessary to establish a common set of rules and regulations across Canada for each of the fuels in order to ensure the consumer a safe, environmentally clean fuel source as well as provide competitive equity among the producers and marketers involved.

B.2 Emission Control Strategies

Although Canada is still at the development stage of emission control regulations, the Canadian Federal Government is currently involved in a number of studies which are examining the emissions generated from a variety of sources including on-highway vehicles. Factors such as fuel type, engine size and type, age, tuning, emission control devices, temperature, speed and load must all be taken into consideration.

A new controls package being jointly examined by Environment Canada and Transport Canada to curtail the effects of emissions from internal combustion engines that burn fossil fuels "may reduce by up to 30 percent, emissions (VOCs) which contribute to smog and acid rain. It could also cap CO₂ emissions, which cause global warming, and will reduce toxins produced by the use of motor fuels", stated Environment Minister Lucien Bouchard.¹ The goal for carbon dioxide emissions was to reduce current levels by 20 percent by 2005.

The standards established in 1987 and 1988 under the Motor Vehicle Safety Act may be capable of lowering air pollution from on-road vehicles over the next decade. As transportation and industrial demands for gasoline and diesel fuel continue to increase, the standards will need to be enhanced to prevent increasing NO_x and VOC emissions.

Ideal combustion of a hydrocarbon fuel requires the perfect proportions of fuel and oxygen burning completely at the correct temperature. Under these conditions, the only emissions would be CO_2 , water (H_2O), and N_2 . This seldom occurs however, as the fuel/oxygen proportions in the combustion chamber may be incorrect and oxidation incomplete. The result is that pollutants are produced.

Carbon monoxide, toxic to humans, is a result of incomplete combustion. More complete combustion, which would likely involve hotter temperatures, would oxidize the CO and produce CO_2 . Unburned hydrocarbons, which can react with NO_x in moisture and sunlight and create smog or acid rain, can be the result of uneven distribution of the fuel in the combustion chamber. Nitrogen oxides, on the other hand, are not a result of either incomplete combustion or uneven distribution of the fuel/oxygen mixture. The nitrogen in the air remains uncombined in the combustion process at lower temperatures. However, as temperatures increase, oxidation takes place and NO_x is created. Particulates, which carry carcinogenic components to the human lungs, result from incomplete combustion. During this process, soot, unoxidized carbon from diesel fuel, and ash from burnt lubricating oil form tiny particles that become the nuclei around which other by-products such as sulphates and unburned hydrocarbons form.²

In the past, regulations have been designed and implemented to limit the emissions of carbon monoxide, hydrocarbons and nitrogen oxides being produced by both automobile spark ignition and diesel engines. The latest proposals for legislative action have indicated much stricter control requirements for particulates. Tables B.1 through B.8 outline the current and proposed legislation for Canada as of January 1990. Tables B.9 and B.10 provide a comparative summary between Canadian current and proposed standards and those imposed by the U.S. Clean Air Act.

B.3 Natural Gas and Propane

As well as fuel specifications, the National Standard of Canada regulates the control, installation and storage of NGV and

TABLE B.1
LIGHT-DUTY VEHICLES, GASOLINE AND
GASEOUS FUELS
(grams per mile)

	Current	Proposed	EPA ^a	CARB
HC	0.41	0.25 ^b	0.41	0.25 ^c
CO	3.4	3.4	3.4	3.4 ^d
CO ₂	-	320 ^e 250 ^f	-	-
NO _x	1.0	0.4	1.0	0.4 ^g
Evap. ^h HC	2.0	2.0	2.0	2.0 ⁱ
Crankcase ^j	0.0	0.0	0.0	0.0 ⁱ

SOURCE: Federal/Provincial Long Range Transport of Air Pollutants (LRTAP) Steering Committee, Canadian Council of Ministers of the Environment (CCME), "Control Technologies for Management of Nitrogen Oxides (NO_x) and Volatile Organic Compounds (VOC) in Canada," Work Sub-Group 6.1 Report, Mobile Sources-NO_x and VOC, prepared by Public Consultation Multistakeholder Work Sub-Group on NO_x/VOC Control Technologies, January 1990.

A 0.25 gpm HC and a 3.4 gpm CO standards have been proposed by California with an effective date of 1992. EPA is also considering a 0.25 gpm HC standard but no definite date for a NPRM exists at this time. The proposed Canadian standards for HC and CO could be technology forcing as a function of U.S. developments. Technical information to support a Canadian analysis will be limited.

The Canadian proposal extends the emission standards to propane and CNG, therefore appropriate test methods will have to be adopted.

The incorporation of a CO₂ emission standard is also unique to Canada. This standard effectively legislates the Company Average Fuel Consumption target (CAFC) of the voluntary program. The CO₂ standard is set at a level representing the status quo in fuel consumption performance. A CO₂ standard representing a 20 percent reduction in fleet fuel consumption should be announced for 2000 to 2005 and be studied at this time.

^aThe EPA emission standards for LDV apply to the 1987 and subsequent model years.

^bThis is a non-methane hydrocarbon standard.

^cThe CARB has proposed a 0.25 g/mile non-methane HC standard for LDV. The current standard is 0.41 g/mile.

^dA 7.0 g/mile CO standard is the current standard in California. However, a 3.4 g/mile CO standard has been proposed for 1992.

^eThis standard may be met on an individual or company average basis.

^fThis standard may be met on a individual or company average basis. This standard applies to the 2005 and later model years.

^gAt least 50 percent of passenger car sales must comply with the 0.4 g/mile NO_x standard in the 1989 model year, and at least 90 percent of passenger car sales must comply with the standard in the 1990 through 1993 model years. Beginning in 1994, all passenger cars must meet the 0.4 g/mile NO_x standard.

^hThe evaporative emission standards are on a g/test basis.

ⁱThis is a current standard and a future standard.

^jNo crankcase emissions are permitted.

TABLE B.2
LIGHT-DUTY VEHICLES, DIESEL
(grams per mile)

	Current	Proposed	EPA ^a	CARB ^a
HC	0.41	0.25 ^b	0.41	0.25 ^c
CO	3.4	3.4	3.4	3.4 ^d
CO ₂	-	320 ^e 250 ^f	-	-
NO _x	1.0	0.4	1.0	0.4 ^g
Particulates	0.2 ^h	0.08	0.2 ^h	0.08 ⁱ

SOURCE: Federal/Provincial Long Range Transport of Air Pollutants (LRTAP) Steering Committee, Canadian Council of Ministers of the Environment (CCME), "Control Technologies for Management of Nitrogen Oxides (NO_x) and Volatile Organic Compounds (VOC) in Canada," Work Sub-Group 6.1 Report, Mobile Sources-NO_x and VOC, prepared by Public Consultation Multistakeholder Work Sub-Group on NO_x/VOC Control Technologies, January 1990.

Comments made on the HC, CO, and CO₂ standards proposed for Canadian study in Amendment Number 12 also apply here.

The proposed NO_x and particulate standards are already in place in California. However, compliance with the NO_x standard by all LDV (diesel) is not required until 1994.

^aThe EPA emission standards for LDV apply to the 1987 subsequent model years.

^bThis is a non-methane hydrocarbon standard.

^cThe CARB has proposed a 0.25 g/mile non-methane HC standard for LDV. The current standard is 0.41 g/mile.

^dA 7.0 g/mile CO standard is the current standard in California. However, a 3.4 g/mile CO standard has been proposed for 1992.

^eThis standard may be met on an individual or company average basis.

^fThis standard may be met on an individual or company average basis. This standard applies to the 2005 and later model years.

^gAt least 50 percent of passenger car sales must comply with the 0.4 g/mile NO_x standard in the 1989 model year, and at least 90 percent of passenger car sales must comply with the standard in the 1990 through 1993 model years. Beginning in 1994, all passenger cars must meet the 0.4 g/mile NO_x standard.

^hAverage procedures may apply in order to meet the standard.

ⁱThe 0.8 g/mile California particulate standard applies to all passenger cars for the 1989 and subsequent years.

TABLE B.3
LIGHT-DUTY TRUCKS,^a GASOLINE AND
GASEOUS FUELS
(grams per mile)

	Current	Proposed	EPA ^b	CARB ^c
HC	0.80	0.25 ^{d,e}	0.41 ^d	0.25 ^{d,e}
CO	10 ^{d,g}	0.32 ^{e,f} 3.4 ^d 4.4 ^f	0.50 ^g 10.0 ^{d,g}	0.32 ^{e,f} 3.4 ^{d,e} 4.4 ^{e,f}
CO ₂	-	400 ^h , 320 ⁱ 460 ^j , 360 ^k	-	-
NO _x	1.2 ^d 1.7 ^g	0.4 ^d 1.0 ^f	1.2 ^{d,l} 1.7 ^{g,l}	0.4 ^{d,m} 1.0 ^f
Evap. ⁿ HC	2.0	2.0	2.0	2.0 ⁱ
Idle CO (%)	0.50	0.50	0.50	0.50
Crankcase Emissions ^p	0.0	0.0	0.0	0.0

SOURCE: Federal/Provincial Long Range Transport of Air Pollutants (LRTAP) Steering Committee, Canadian Council of Ministers of the Environment (CCME), "Control Technologies for Management of Nitrogen Oxides (NO_x) and Volatile Organic Compounds (VOC) in Canada," Work Sub-Group 6.1 Report, Mobile Sources-NO_x and VOC, prepared by Public Consultation Multistakeholder Work Sub-Group on NO_x/VOC Control Technologies, January 1990.

The changes noted here require a re-definition of LDT's to their traditional definition of trucks with a Gross Vehicle Weight Rating (GVWR) of 6000 pounds or less.

The standards proposed for study in Canada are fairly straight forward and low risk in that all the proposed standards are already in place as final rules in California with the exception of the HC and CO standards which are only at the proposed stage at this time for California.

The CO₂ is unique to Canada. It is set at the status quo with respect to fuel economy targets for light- and medium-duty trucks under the U.S. CAFE program.

^aLight-duty trucks have a GVWR not exceeding 6000 pounds.

^bThe EPA emission standards apply to 1988 and subsequent model year LDT with the exception of the HC standard which is a proposed standard.

^cUnless otherwise noted, the standards are both current and future California standards.

^dApplies to LDT having a loaded vehicle weight not exceeding 3750 pounds.

^eCARB has proposed a 0.25 gpm and 0.32 gpm non-methane HC standard. CARB has also proposed a 3.4 gpm and 4.4 gpm CO standard. The HC and CO proposal is scheduled for presentation at a mid-1990 Board Hearing and includes a 1992 implementation date.

^fApplies to LDT having a loaded vehicles weight between 3751-5750 pounds.

^gApplies to LDT having a loaded vehicles weight greater than 3750 pounds.

^bThis standard applies to two-wheel drive light-duty trucks and medium-duty vehicles and may be met on an individual or company average basis. This standard applies to the 2005 and later model years.

^cThis standard applies to four-wheel drive light-duty trucks and medium-duty vehicles and may be met on an individual or company average basis.

^dThis standard applies to four-wheel drive light-duty trucks and medium-duty vehicles and may be met on an individual or company average basis. This standard applies to the 2005 and later model year.

^eEmissions averaging may apply.

^fAt least 50 percent of LDT (0-3750 pounds LVW) must comply to the 0.4 g/mile NO_x standard in the 1989 model year; at least 85 percent must comply in the 1990 through 1993 model year and finally all LDT (0-3750 pounds LVW) must comply to this standard beginning in the 1994 model year.

^gThe evaporative HC standard is on a g/test basis.

^hNo crankcase emissions are permitted.

TABLE B.4
LIGHT-DUTY TRUCKS,^a DIESEL
(grams per mile)

	Current	Proposed	EPA ^b	CARB ^c
HC	0.80	0.25 ^{d,e}	0.41 ^d	0.25 ^{d,e}
CO	10 ^{d,g}	0.32 ^{e,f} 3.4 ^d 4.4 ^f	0.50 ^g 10.0 ^{d,g}	0.32 ^{e,f} 3.4 ^{d,e} 4.4 ^{e,f}
CO ₂	-	400 ^h , 320 ⁱ 460 ^j , 360 ^k	-	-
NO _x	1.2 ^d 1.7 ^g	0.4 ^d 1.0 ^f	1.2 ^{d,l} 1.7 ^{g,l}	0.4 ^{d,m} 1.0 ^f
Particulates	.26	0.08	0.26 ^l	0.08 ⁿ
Crankcase Emissions ^o	0.0	0.0	0.0	0.0

SOURCE: Federal/Provincial Long Range Transport of Air Pollutants (LRTAP) Steering Committee, Canadian Council of Ministers of the Environment (CCME), "Control Technologies for Management of Nitrogen Oxides (NO_x) and Volatile Organic Compounds (VOC) in Canada," Work Sub-Group 6.1 Report, Mobile Sources-NO_x and VOC, prepared by Public Consultation Multistakeholder Work Sub-Group on NO_x/VOC Control Technologies, January 1990.

Comments noted under Amendment Reference Number 15 (LDT, gasoline, gaseous fuels) also apply here.

^aLight-duty trucks have a GVWR not exceeding 6000 pounds.

^bThe EPA emission standards apply to 1988 and subsequent model year LDT with the exception of the HC standard which is a proposed standard.

^cUnless otherwise noted, the standards are both current and future California standards.

^dApplies to LDT having a loaded vehicle weight not exceeding 3750 pounds.

^eCARB has proposed a 0.25 gpm and 0.32 gpm non-methane HC standard. CARB has also proposed a 3.4 gpm and 4.4 gpm CO standard. The HC and CO proposal is scheduled for presentation at a mid-1990 Board Hearing and includes a 1992 implementation date.

^fApplies to LDT having a loaded vehicles weight between 3751-5750 pounds.

^gApplies to LDT having a loaded vehicles weight greater than 3750 pounds.

^hThis standard applies to two-wheel drive light-duty trucks and medium-duty vehicles and may be met on an individual or company average basis.

ⁱThis standard applies to a two-wheel drive light-duty trucks and medium-duty vehicles and may be met on an individual or company average basis. This standard applies to the 2005 and later model year.

^jThis standard applies to four-wheel drive light-duty trucks and medium-duty vehicles and may be met on an individual or company average basis.

^kThis standard applies to four-wheel drive light-duty trucks and medium-duty vehicles and may be met on an individual or company average basis. This standard applies to the 2005 and later model years.

^lEmissions averaging may apply.

^mAt least 50 percent of LDT (0-3750 pounds LVW) must comply to the 0.4 g/mile NO_x standard in the 1989 model year; at least 85 percent must comply in the 1990 through 1993 model year and finally all LDT (0-3750 pounds LVW) must comply to this standard beginning in the 1994 model year.

ⁿThe evaporative HC standard is on a g/test basis.

^oNo crankcase emissions are permitted.

TABLE B.5
MEDIUM-DUTY VEHICLES,^a GASOLINE AND
GASEOUS FUELS
(grams per mile)

	Current	Proposed	EPA ^b	CARB ^c
HC	0.80	0.25 ^d 0.32 ^e 0.50 ^f	- - -	0.25 ^d 0.32 ^e 0.60 ^f
CO	10.0	3.4 ^d 4.4 ^e 9.0 ^f	- - -	3.4 ^d 4.4 ^e 9.0 ^f
CO ₂	-	400 ^g , 320 ^h 460 ⁱ , 360 ^j	-	-
NO _x	1.2 ^d 1.7 ^e 1.7 ^f	0.4 ^d 1.0 ^e 1.5 ^f	- - -	0.4 ^{d,k} 1.0 ^e 1.5 ^f
Evap. ^l HC	2.0	2.0	-	2.0
Idle CO (%)	0.50	0.50	-	0.50
Crankcase Emissions ^m	0.0	0.0	-	0.0 ⁱ

SOURCE: Federal/Provincial Long Range Transport of Air Pollutants (LRTAP) Steering Committee, Canadian Council of Ministers of the Environment (CCME), "Control Technologies for Management of Nitrogen Oxides (NO_x) and Volatile Organic Compounds (VOC) in Canada," Work Sub-Group 6.1 Report, Mobile Sources-NO_x and VOC, prepared by Public Consultation Multistakeholder Work Sub-Group on NO_x/VOC Control Technologies, January 1990.

Medium-duty trucks would be a new class of trucks for Canada. This category would encompass the upper end of the current light truck class (i.e., 6001 to 8500 pounds GVWR) consistent with California practice. The finer breakdown of trucks into three classes (light, medium, heavy) as opposed to the current two classes (light, heavy) makes possible tighter standards as a function of vehicle weight.

The standards proposed for study in Canada have either already been adopted in California or are expected to be in place by the mid-1990's (i.e., the HC and CO standards have been proposed for 1992). The exception to this is the 0.5 gpm HC standard proposed for Canadian MDT's with a loaded vehicle weight greater than 5750 pounds. An equivalent standard to that proposed by Canada has also been proposed by the EPA.

The risk associated with the proposed Canadian standards is low.

^aMedium-duty vehicles have a GVWR greater than 6000 pounds but not exceeding 8500 pounds.

^bThe EPA does not regulate medium-duty vehicles as a distinct vehicle class; they are included in their light-duty truck class.

^cThe CARB HC and CO standards for the 0-3750 pounds and 3751-5750 pounds. LVM fractions of the MDV class have been proposed for 1992. The

remaining standards, with the exception of the NO_x standard for the 0-3750 pounds fraction (see i), are current CARB standards.

^dApplies to MDV having a loaded vehicle weight between 0-3750 pounds.

^eApplies to MDV having a loaded vehicle weight between 3751-5750 pounds.

^fApplies to MDV having a loaded vehicle weight greater than 5750 pounds.

^gThis standard applies to two-wheel drive light-duty trucks and medium-duty vehicles and may be met on an individual or company average basis.

^hThis standard applies to two-wheel drive light-duty trucks and medium-duty vehicles and may be met on an individual or company average basis. This standard applies to the 2005 and later model years.

ⁱThis standard applies to four-wheel drive light-duty trucks and medium-duty vehicles and may be met on an individual or company average basis.

^jThis standard applies to four-wheel drive light-duty trucks and medium-duty vehicles and may be met on an individual or company average basis. This standard applies to the 2005 and later model years.

^kAt least 50 percent of MDV sales (0-3750 pounds LVW) must comply with the 0.4 g/mile NO_x standard in the 1989 model year, and at least 85 percent must comply with this standard in the 1990 through 1993 model years. Beginning in 1994, all MDV (0-3750 pounds LVW) must meet the 0.4 g/mile NO_x standard.

^lThe evaporative emission standards is on a g/test basis.

^mNo crankcase emissions are permitted.

TABLE B.6
MEDIUM-DUTY VEHICLES,^a DIESEL
(grams per mile)

	Current	Proposed	EPA ^b	CARB ^c
HC	0.80	0.25 ^d 0.32 ^e 0.50 ^f	- - -	0.25 ^d 0.32 ^e 0.60 ^f
CO	10.0	3.4 ^d 4.4 ^e 9.0 ^f	- - -	3.4 ^d 4.4 ^e 9.0 ^f
CO ₂	-	400 ^g , 320 ^h 460 ⁱ , 360 ^j	-	-
NO _x	1.2 ^d 1.7 ^e 1.7 ^f	0.4 ^d 1.0 ^e 1.5 ^f	- - -	0.4 ^{d,k} 1.0 ^e 1.5 ^f
Particulates Crankcase ^m Emissions	0.26 0.0	0.08 0.0	- -	0.08 ^l 0.0

SOURCE: Federal/Provincial Long Range Transport of Air Pollutants (LRTAP) Steering Committee, Canadian Council of Ministers of the Environment (CCME), "Control Technologies for Management of Nitrogen Oxides (NO_x) and Volatile Organic Compounds (VOC) in Canada," Work Sub-Group 6.1 Report, Mobile Sources-NO_x and VOC, prepared by Public Consultation Multistakeholder Work Sub-Group on NO_x/VOC Control Technologies, January 1990.

As noted from Amendment Reference Number 18.

The CO₂ Standard is unique to Canada and is set at levels consistent with EPA regulated CAFE requirements for light trucks. Compliance would be determined on a per vehicle basis, on the basis of a company average within the vehicle class, or on the basis of a company average of both light- and medium-duty trucks. The analysis necessary to support the CO₂ standard will be difficult.

^aMedium-duty vehicles have a GVWR greater than 6000 pounds but not exceeding 8500 pounds.

^bThe EPA does not regulate medium-duty vehicles as a distinct vehicle class; they are included in their light-duty truck class.

^cThe CARB HC and CO standards for the 0-3750 pounds and 3751-5750 pounds. LVM fractions of the MDV class have been proposed for 1992. The remaining standards, with the exception of the NO_x standard for the 0-3750 pounds fraction (see i), are current CARB standards.

^dApplies to MDV having a loaded vehicle weight between 0-3750 pounds.

^eApplies to MDV having a loaded vehicle weight between 3751-5750 pounds.

^fApplies to MDV having a loaded vehicle weight greater than 5750 pounds.

^gThis standard applies to two-wheel drive light-duty trucks and medium-duty vehicles and may be met on an individual or company average basis.

^hThis standard applies to two-wheel drive light-duty trucks and medium-duty vehicles and may be met on an individual or company average basis. This standard applies to the 2005 and later model years.

^jThis standard applies to four-wheel drive light-duty trucks and medium-duty vehicles and may be met on an individual or company average basis.

^jThis standard applies to four-wheel drive light-duty trucks and medium-duty vehicles and may be met on an individual or company average basis. This standard applies to the 2005 and later model years.

^kAt least 50 percent of MDV sales (0-3750 pounds LVW) must comply with the 0.4 g/mile NO_x standard in the 1989 model year, and at least 85 percent must comply with this standard in the 1990 through 1993 model years. Beginning in 1994, all MDV (0-3750 pounds LVW) must meet the 0.4 g/mile NO_x standard.

^lThe evaporative emission standards is on a g/test basis.

^mNo crankcase emissions are permitted.

TABLE B.7
HEAVY-DUTY VEHICLES, GASOLINE AND
GASEOUS FUELS
(g/bhp-hr)

	Current	Proposed	EPA ^a	CARB ^a
HC	1.1 ^b 1.9 ^c	1.1 ^b 1.9 ^c	1.1 ^b 1.9 ^c	1.1 ^b 1.9 ^c
CO	14.4 ^b 37.1 ^c	14.4 ^b 27.1 ^c	14.4 ^b 37.1 ^c	14.4 ^b 37.1 ^c
NO _x	6.0 ^d	5.0 ^d	5.0 ^{d,e}	5.0 ^e
Evap. ^f	3.0 ^b 4.0 ^c	3.0 ^b 4.0 ^c	3.0 ^b 4.0 ^c	2.0 ^b 2.0 ^c
Idle CO (%)	0.50	0.50	0.50	0.50
Crankcase Emissions ^g	0.0	0.0	0.0	0.0

SOURCE: Federal/Provincial Long Range Transport of Air Pollutants (LRTAP) Steering Committee, Canadian Council of Ministers of the Environment (CCME), "Control Technologies for Management of Nitrogen Oxides (NO_x) and Volatile Organic Compounds (VOC) in Canada," Work Sub-Group 6.1 Report, Mobile Sources-NO_x and VOC, prepared by Public Consultation Multistakeholder Work Sub-Group on NO_x/VOC Control Technologies, January 1990.

With the exception of NO_x, the proposed Canadian standards are already in place in Canada, EPA, and CARB. The NO_x standard will be tightened for the United States for the 1991 model year. There is little risk in adopting the proposed standards in Canada for the mid-1990s.

For Canada, the new standards would be applied to gaseous fuel-powered HDVs. This would require development of appropriate gaseous fuel test methods.

^aThe EPA and CARB emission standards for this class apply to 1988 and subsequent model years, with the exception of the NO_x standards.

^bApplies to HDV having a GVWR not exceeding 14,000 pounds.

^cApplies to HDV having a GVWR greater than 14,000 pounds.

^dEmissions averaging procedures may apply in meeting the standard.

^eThe 5.0 g/bhp-hr NO_x standard applies to the 1991 and subsequent model years.

^fThe evaporative emission standards are on a g/test basis.

^gNo crankcase emissions are permitted.

TABLE B.8
HEAVY-DUTY VEHICLES, DIESEL
(g/bhp-hr)

	Current	Proposed	EPA ^a	CARB ^a
HC	1.3	1.3	1.3	1.3
CO	15.5	15.5	15.5	15.5
NO _x	6.0 ^b	5.0 ^b	5.0	6.0
Particulates	0.60 ^b	0.10 ^b	0.10 ^{b,d}	0.10 ^d
Crankcase				
Emissions ^e	0.0 ^e	0.0 ^e	0.0 ^e	0.0 ^e

SOURCE: Federal/Provincial Long Range Transport of Air Pollutants (LRTAP) Steering Committee, Canadian Council of Ministers of the Environment (CCME), "Control Technologies for Management of Nitrogen Oxides (NO_x) and Volatile Organic Compounds (VOC) in Canada," Work Sub-Group 6.1 Report, Mobile Sources-NO_x and VOC, prepared by Public Consultation Multistakeholder Work Sub-Group on NO_x/VOC Control Technologies, January 1990.

The proposed standards represent a tightening of NO_x and particulate standards from current levels. The proposed NO_x standard will be in place in the U.S. for 1991, the particulate standard for 1994. There is still some uncertainty that the particulate standard will be met in the United States for 1994. The technology to meet the particulate standard and its cost are still not well defined. This will complicate the analysis of this initiative. The overall risk with this amendment is still high.

^aThe EPA and CARB emission standards apply to 1988 and subsequent model years, with the exception of the NO_x standards.

^bEmissions averaging procedures may apply in meeting the standard.

^cThe 5.0 g/bhp-hr NO_x standard applies to the 1991 and subsequent model years.

^dThe 0.10 g/bhp-hr NO_x particulate standard applies to the 1994 and subsequent model years.

^eNo crankcase emissions are permitted; however a waiver to this standard may be issued to non-naturally aspirated engines.

TABLE B.9
CURRENT AND PROPOSED VEHICLE EMISSIONS STANDARDS
CANADA AND THE UNITED STATES
LIGHT- AND MEDIUM-DUTY VEHICLES

	NMHC g/mile	HC g/mile	CO g/mile	NO _x g/mile	Particulates g/mile	Evaporatives g/test
Canadian and American Current Standards						
Passenger Cars		0.41	3.4	1.0	0.2 ^a	2.0
Light-Duty Truck (up to 3750 lb. GVWR)		0.8	10.0	1.2	0.26	2.0
Medium-Duty Truck (over 3750 lb. GVWR)		0.8	10.0	1.7	0.26	2.0
Canadian Proposed Standards						
Passenger Cars		0.25	3.4	0.4	0.08 ^a	2.0
Light-Duty Truck (up to 3750 lb. GVWR)		0.25	3.4	0.4	0.08	2.0
Medium-Duty Truck (3751 to 5750 lb. GVWR)		0.32	4.4	1.0	0.08	2.0
Medium-Duty Truck (over 5751 lb. GVWR)		0.5	9.0	1.5	0.08	2.0
American Proposed Standards						
Passenger Cars	0.25	--	3.4	0.4	0.08 ^a	2.0
Light-Duty Truck (up to 3750 lb. GVWR)	0.25	--	3.4	0.4	0.08	2.0
Medium-Duty Truck (3751 to 5750 lb. GVWR)	0.32	0.38	4.4	0.7	--	
Medium-Duty Truck (5751 to 8500 lb. GVWR)	0.39	0.46	5.0	1.1	0.12	

SOURCE: Energy, Mines and Resources Canada, 1991.

^aDiesel.

TABLE B.10
PHASE-IN OF NEW EMISSION STANDARDS
FOR UNITED STATES PASSENGER CARS

Level (grams per mile)		Model Year (percent)				
		1994	1995	1996	1997	1998
NO _x	0.4 gasoline	40	80	100	100	100
NO _x	1.0 diesel	100	100	100	100	100
NMHC	0.32	40	80	60	20	0
	0.25	0	0	40	80	100
CO	3.4	100	100	100	100	100
	10.0 cold 20°F	40	80	100	100	100

SOURCE: Energy, Mines and Resources Canada, 1991.

NOTE: Phasing-in is not allowed in Canada under the Motor Vehicle Safety Act. The final date for 100 percent compliance with these new standards is 1996, but a similar phase-in in 1994 and 1995 is expected in Canada as the same models introduced in the United States are introduced into the Canadian market.

propane. The national standards were developed by the Canadian Gas Association and provide the requirements for both NGV and propane system and component testing. Mechanics installing natural gas conversion kits must be certified by the appropriate provincial authority, and the equipment associated with natural gas and propane conversions must be tested and approved by the CGA.

B.3.1 Natural Gas

CAN1-12.3-M84, Natural Gas Vehicle Fuel System Components. Section 1.1.1 states that this standard applies to the construction and performance of new, compressed natural gas fuel system components providing motive power for highway vehicles utilizing internal combustion engines.

CAN1-B149.1-M80, Installation Code for Natural Gas Burning Appliance and Equipment. This standard defines the technical and safety requirements associated with any natural gas installation.

Amendment No. 1 to CAN1-B149.1M80, Installation of Compressed Natural Gas Fuel Systems and Containers on Highway Vehicles, and Requirements for Refuelling Stations. This amendment outlines the requirements for the installation of NGV fuel systems and containers on highway vehicles and also defines the requirements for NGV refuelling stations.

B.3.2 Propane

CAN-12.2-M84, Propane Fuel System Components for Use on Highway Vehicles. Section 1.1.1 states that this standard applies to the construction and performance of new propane fuel system components providing motive power for highway vehicles utilizing internal combustion engines.

CAN1-B149.2-M86, Propane Installation Code. This standard defines the technical and safety requirements associated with any propane installation.

There are several other standards, relating to the quality of materials used (fuel tanks, supply lines and fittings, etc.) in natural gas and propane installations, which can be obtained from the Canadian Gas Association in Don Mills, Ontario.

B.4 Alcohol Fuels

A formal set of standards for oxygenated fuels has been developed for Canada by CGSB. The new standards were not available at time of writing. Oxygenates, blended with gasoline, exhibit different characteristics than they do as pure substances. The new CGSB Standards will specify the requirements for a number of these characteristics which affect gasolines and gasoline blends. Three specific standards of concern to gasoline producers are: octane rating, volatility, and oxygen content.

B.4.1 Octane Requirements

An "octane rating" is a measurement of the ignition characteristics of gasolines. The most frequently used measurement to determine octane levels is called the "antiknock index" or "road octane measure". The antiknock index is defined as the average of the Research (R) and Motor (M) octane number for fuel, (i.e., $(R+M)/2$). The research octane number (RON) measures a fuel's rating under low-speed driving conditions. The motor octane number (MON) measures a fuel's characteristics under high-speed, high-load conditions. Since the MON test conditions are more severe, it is normally the most critical indicator of gasoline quality.³

The octane blending values for alcohols are very dependent on the chemical composition of the hydrocarbons into which they are blended, as well as vehicle operating conditions. Oxygenates generally have a high research octane number and a lower motor octane number. This would suggest that for some gasolines under high engine loads, the addition of ethanol and methanol might not improve the octane rating at all. Refiners aspiring to achieve specific octane ratings in their fuels must take all of these factors into account.⁴

Gasoline produced with an inadequate octane level will result in engine knock or audibly, a "ping". In internal combustion engines, fuel and air are drawn into the combustion cylinders where they are compressed and then ignited by a spark. A "knock" or "pinging" occurs if some of the air-fuel mixture auto-ignites before the ignition spark. The result is excessive pressure from the vibration of the gas in the cylinder, thus creating the pinging sound. Engine knock is a function of fuel characteristics, engine design and driving conditions and is undesirable because fuel economy is lost, engine performance is unsatisfactory and damage to the engine's head gaskets, valves and piston heads may occur if the condition is not corrected.

In the past, tetraethyl lead has been a cheap, and therefore preferred, addition to boost the octane levels in fuels. However, as of January 1, 1987, the allowable level of lead was reduced from 0.77 to 0.29 grams per litre. Effective December 1990, the use of lead in gasoline was eliminated in Canada. This has meant that Canadian refiners are either requiring other additives or more severe refining of petroleum fuels to supplement octane levels. Alcohols, as well as ethers, have higher octane values than typical gasolines. The actual blending octanes can vary as much as ± 8 octane numbers, depending upon the oxygenate, as well as the base gasoline stock used.⁵ The blending value of oxygenates will be more significant in base fuels with lower octane numbers as well as decreasing aromatic and olefin hydrocarbon content; therefore, alcohol blending values would be higher for "regular" gasolines than for "premium" gasolines.

B.4.2 Volatility

Volatility measures the rate at which a fuel evaporates, or changes from liquid to a vapour, at a specified temperature and pressure. Volatility specifications are required to ensure smooth acceleration and proper starting and warming of automobile engines in cold weather conditions and at varying altitudes. Fuels which do not reach minimum vapour pressure specifications may have trouble starting at low temperatures. Excessive vapour pressure, on the other hand, can result in "vapour lock", which in turn causes the automobile to stall. Refiners, therefore, must and do adjust the volatility of their gasoline to meet engine requirements at different seasons of the year.

Since fuel must be vapourized in order to burn properly in an internal combustion engine, the seasonal and geographical distribution of the Standard volatility classes is determined by the "ambient" temperature in that region. This "ambient" temperature factor has a major effect on the fuel volatility requirements because alcohol-gasoline blends will evaporate more readily than unblended gasolines at higher ambient temperatures, whereas at lower temperatures, the volatility of gasoline can decrease if alcohol is added.

There are two methods of measurement used by the CGSB to determine the volatility of gasolines. The RVP measures fuel evaporation at 100°F (37.8°C) and is a good determinant of the fuel's "front-end" volatility, which is significant in regards to startability, vapour lock and evaporative emissions. The second method, the American Society for Testing and Materials (ASTM) D86 distillation curve, measures the relative volatility of all the fuel constituents from the initial boiling point to the end point.⁶ In other words, the CGSB

and ASTM distillation specifications reveal the boiling point at which a percentage of the fuel evaporates.

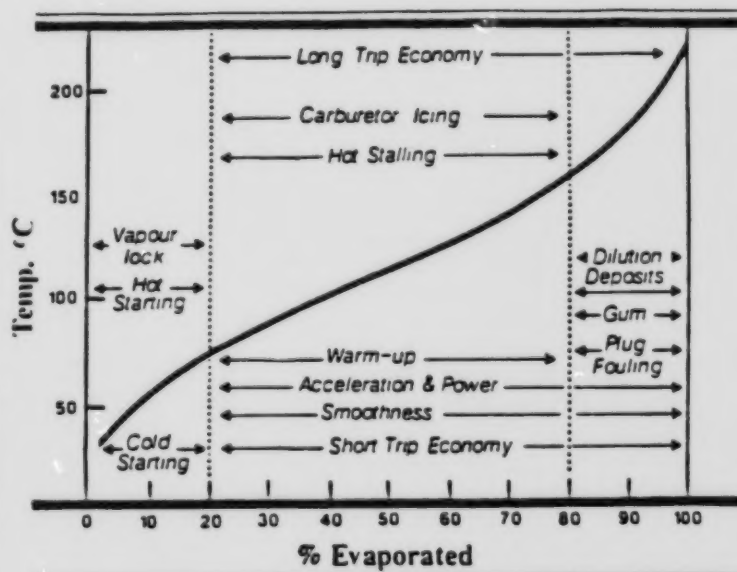
It is the distillation specifications, as well as the RVP specifications, which control the volatility of gasolines. The vapour pressure of a fuel is important because of its effect on both the vehicle's driveability and the amount of evaporative emissions released into the atmosphere. Higher evaporative emissions from alcohol-gasoline blends may result in an environmental problem if these fuels are allowed higher vapour pressures than other gasolines.⁷ Adding an oxygenate into gasoline tends to reduce the front-end distillation temperatures below those of the base gasoline, even though alcohols by themselves are not particularly volatile. However, the relationship which exists between blending vapour pressure of alcohol oxygenates and the concentration of alcohol in gasolines is non-linear. The first increment of alcohol to gasoline sharply increases the vapour pressure of the blend, but beyond alcohol additions of 3 percent the effect on the gasoline blend vapour pressure becomes negligible.⁸ The lighter alcohols, such as methanol and ethanol, when blended with gasoline, result in a disproportionately high increase in the vapour pressure of the fuel at low temperatures whereas MTBE, as an ether, and the heavier alcohols do not appear to have this effect.⁹

The higher fuel volatility which results when either methanol or ethanol is the blending agent, as well as the decreased freezing problems stemming from alcohol's affinity for water, combine to improve vehicle driveability in wintertime (if added to a gasoline not already at maximum RVP), but could lead to vapour lock in warmer summer conditions. In order for refiners who produce oxygenated gasolines with lighter alcohols to have their products meet CGSB volatility specifications, they must "tailor" the gasoline to control the vapour pressures. This can be accomplished easily by changing the percentage of butane in the fuel because butane has a high RVP. However, backing out butane, which is an inexpensive, readily-available high octane component, can result in a significant cost to the refiner. Figure B.1 illustrates the effects which volatility has on engine performance.

B.4.3 Oxygen Content

Automobile engines take in a certain amount of oxygen from the air in order for combustion to occur. However, too much oxygen results in poor combustion. Tests performed in the United States on engines designed to run on gasoline have determined that up to 3.7

Figure B.1
Effects of Volatility on
Engine Performance



SOURCE: Energy, Mines and Resources Canada, *Discussion Paper on Oxygenated Gasolines*, Cat. no. M92-19/1986E (Ottawa: Ministry of Supply and Services, 1986), p. 19.

percent oxygen by weight can be included in a fuel without affecting engine performance. The amount of oxygenate being added to a fuel must be limited as oxygenated gasolines are, in effect, partially combusted hydrocarbons. Therefore, more oxygen is available to complete the combustion process than would be the case if straight gasoline was utilized.

The proposed CGSB standards for oxygenated fuels set 3.7 percent as the allowed upper limit for oxygen content. To maintain this requirement in oxygenated gasolines, two criteria have been established:

- (i) Methanol content cannot exceed 5 percent by volume; and
- (ii) ethanol content cannot exceed 10 percent by volume.¹⁰

B.4.4 Gasoline Extenders or Octane Enhancers

Octane enhancers are substances that can be added to fuel to raise the octane number, and therefore act as a substitute for tetraethyl lead. Gasoline extenders are those oxygenates which can themselves have value as a fuel but are most commonly used as blending additives, in greater volume than octane enhancers. A particular oxygenate can, therefore, be considered an octane enhancer or a gasoline extender depending on how it is used. Oxygenates which can be utilized include methanol, ethanol, MTBE, and ETBE.

It is worthwhile noting that the value of oxygenates as a fuel in the market-place is dependent on whether it is considered a gasoline extender or an octane enhancer. As a gasoline extender, gasoline marketers surveyed today would not purchase alcohol unless it could be acquired at a substantial discount to gasoline. The size of discount would be determined by the cost of adjusting the gasoline to maintain volatility standards, perceived consumer response to the final cost, as well as the capital cost involved with integrating the alcohol into the distribution and retail system. It has been suggested that alcohol blends, when considered solely as gasoline extenders, would require a one cent per litre reduction in the rack price. If the alcohol portion were required to contribute 100 percent of this reduction, then the market value of the alcohol component would, in fact, be very low.¹¹

On the other hand, if refiners turn to using alcohols as octane enhancers in response to the elimination of lead in gasoline, there may be sufficient demand to warrant the capital outlay required for production facilities, in which case the market value of alcohol fuels would be much greater.

Footnotes

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⁵Energy, Mines and Resources Canada, *Optimized Linear Program Analysis of the Effect of Oxygenated Fuels on Canadian Oil Refineries*, study prepared by Hycarb Engineering Ltd., TE-86-5 (Ottawa, Ontario, March 1986), p. V-1.

⁶Energy, Mines and Resources Canada, *Discussion Paper on Oxygenated Gasolines*, 1986 Summary, Cat. No. M92-19/1986E (Ottawa, Ontario: Supply and Services Canada, 1986), p. 18.

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⁸Energy, Mines and Resources Canada, *Optimized Linear Program Analysis of the Effect of Oxygenated Fuels on Canadian Oil Refineries*, TE-86-5, prepared by Hycarb Engineering Ltd. (Ottawa, Ontario, March 1986), p. V-2.

⁹*Ibid.*, pp. V-1, V-2.

¹⁰Energy, Mines and Resources Canada, *Discussion Paper on Oxygenated Gasolines*, 1986 Summary, Cat. No. M92-19/1986E (Ottawa, Ontario: Supply and Services Canada, 1986), p. 17.

¹¹St. Lawrence Starch Limited, *Phase I: Pre-feasibility Study for a Comprehensive Alcohols Study for the Province of Alberta*, prepared for Alberta Agricultural Processing Development Branch, Alberta Agricultural Marketing Services Division, November 1986, p. 77.



Appendix C

**UTILIZATION OF ALTERNATIVE FUELS IN
VARIOUS FOREIGN COUNTRIES**



Appendix C

UTILIZATION OF ALTERNATIVE FUELS IN VARIOUS FOREIGN COUNTRIES

C.1 Compressed Natural Gas and Propane

C.1.1 United States

The United States road transportation market is almost entirely dependent on gasoline (84.2 percent), diesel fuel (15.5 percent), and liquefied petroleum gas or propane (0.3 percent).¹ In response to depleting oil resources and concerns for energy security and a cleaner environment, efforts to develop an alternative fuels program have concentrated on methanol and natural gas although propane is being used commercially in the trucking industry and ethanol is being used in low level blends with gasoline.

Propane

Approximately 66 percent of the United States domestic propane is a product of natural gas processing and the remainder a by-product of crude oil refining. Availability has been the principal constraint to broader use of auto-propane. Although 20 billion US gallons of propane were produced domestically in 1985, only 490 million US gallons of propane were consumed by the transportation industry. In fact, between 1983 and 1985, propane use in the transportation sector dropped by 39 percent, from 804 million gallons to less than 490 million gallons. Future increases will be dependent on taxes and incentives.²

Compressed Natural Gas

Interest is growing in the marketing of natural gas vehicles in the United States due to its potential environmental benefits as well as its use as an alternative to imported oil. The United States EPA believes the health of the U.S. population is threatened by the polluting emissions from the 178 million cars, buses and trucks travelling the byways of the American urban and rural areas, burning over 126 billion gallons of gasoline a year. Considered a clean burning alternative fuel, the EPA is analysing the economic and environmental

effects of using compressed natural gas as a fuel for both light and heavy-duty vehicles.

The United States transportation sector relies on oil to meet over 97 percent of its energy requirements. This accounts for over 63 percent of the total United States oil consumption and resulted in a trade deficit of over 47 billion U.S. dollars in 1987.³ United States oil imports rose 9.6 percent between 1987 and 1988, indicating the vulnerability of the United States to oil dependency and the value of utilizing its natural gas supplies which currently exceed oil reserves by 22 percent.⁴

Truck and bus engine manufacturers are striving to manufacture engines which will meet the emissions limits set by the Environmental Protection Agency. As indicated in Appendix B, these vehicle emissions regulations are becoming increasingly restrictive, particularly in regards to particulate emissions. The proposed limitations cannot be met by current conventional engine technology using diesel fuel. The durability and economics of particulate traps installed in diesel exhaust lines have not been fully proven, and provide only a partial solution to the emissions problems.

The GRI is concentrating near-term efforts at developing dedicated natural gas engines for heavy-duty fleet vehicles with high annual mileage demands, in particular urban buses. In a jointly funded program between GRI and the Canadian Gas Association, Cummins Engine Company is working to develop a natural gas fuelled derivative of the L-10 diesel engine, using an open chamber, lean-burn approach. Cummins faces the challenge of optimizing the lean-burn process to limit NO_x emissions while at the same time maintaining power and driveability.⁵

Demonstration testing in Peoria, Illinois on a direct injected natural gas Caterpillar 3400 Series single cylinder engine has indicated that both natural gas engine specific power and natural gas thermal efficiency can be improved to levels equal to the diesel engine.

Hercules Engine Company, in a project also receiving support from GRI, is trying to optimize a four-cylinder, 3.7-litre diesel engine for operation on natural gas. Fast burn or lean burn technology using a compact, open chamber designed for high turbulence and short flame path will be utilized as this is an effective way for smaller, higher speed engines to achieve better efficiency and low emissions.⁶ This research is aimed at the development of dedicated natural gas systems and advanced fuelling systems for vehicles with specific routes

such as school buses and garbage trucks, which return to a central refuelling station each day.

Natural gas for vehicles has been marketed in the United States for almost two decades. There are over twenty United States firms marketing conversion kits. Yet, there are estimated to be only 30,000 natural gas vehicles operating in the country, representing less than one tenth of one percent of the vehicle population. Over half of these natural gas vehicles are owned and operated by natural gas companies, which also own the majority of the 300 natural gas refilling stations. Only nineteen stations have been available to the public for refuelling.⁷ But, on March 1, 1990, Pacific Gas & Electric opened California's first public compressed natural gas refuelling station with plans to open seven more to the public this year. In early June of 1990, Natural Fuels Corp., of which Public Service of Colorado is the majority owner, opened its first public fuelling station at Stapleton Airport in Denver. The company plans on opening seven more public stations by the end of the year, along with twelve for individual company fleets.⁸ Perhaps these initiatives will provide an answer to the "chicken and egg" situation which tends to inhibit vehicle manufacturers from building NGV vehicles when refuelling facilities for these vehicles are few and far between.

Although dedicated natural gas vehicles for both light-, medium- and heavy-duty vehicles are currently being designed and tested by a number of the OEMs, and although recent Federal and State government actions, particularly in non-attainment areas, have provided greater encouragement to convert to natural gas, lower fuel prices and the uncertainty of recovering conversion and refilling costs have inhibited U.S. levels of NGV investment relative to countries such as Canada and New Zealand.

C.1.2 New Zealand

Unlike Canada and the United States, the development of NGV in New Zealand was driven entirely by economics and the desire for energy security. The oil price shocks of the 1970s partnered with a nearly total dependence on imported petroleum, prompted New Zealand to capitalize on its significant natural gas resources by spurring the development of a nationwide NGV industry. The Liquid Fuels Trust Board (LFTB) was formed to determine ways of reducing the use of oil in the transportation industry. By 1986, roughly 48 percent of gasoline demand had been displaced by synthetic gasoline, natural gas and propane.

While initial market growth required government incentives involving vehicle and fuel station incentives, NGV is now mainly supported by the private sector. By 1986, 11 percent of all cars and light trucks (110,000 vehicles) were converted to natural gas and supported by a refuelling network of 400 stations.⁹

New Zealand's NGV industry has had its setbacks, however. This could be expected with the initiation of any new alternative fuel, especially a gaseous fuel trying to penetrate a well defined liquid fuel market. Active support has promoted conversion but not as quickly as was expected. This support was comprised of advertising and publicity, as well as monetary incentives which included a conversion kit grant of NZ \$150 (US \$140 or Cdn \$175), and a grant to service stations for 25 percent of compressor and storage tank costs. Although a set of standards for both vehicle-conversion and refuelling station industries was established, private motorists were reluctant to convert to a technology they were not familiar with.

Finally in 1983, to help overcome the motorists' reluctance to incur the high initial costs attributed to the conversion kits, the Government added a low-interest loan program (NZ \$500, US \$320 to NZ \$5000, US \$3200) which ran for six months to three years. Other important developments were the formation by industry of both the Alternative Fuels Association and the natural gas Federation, as well as a voucher scheme providing motorists with NZ \$300 (US \$200) worth of free natural gas in the two years following conversion. In 1984, an installer registration program was tied to loan eligibility in order to ensure the conversion quality of the installations, about which consumers had been complaining.¹⁰ 1985 recorded a natural gas conversion peak rate of 5480 per month.¹¹

Increased demand for conversions in turn led to technical problems as the conversion industry became unable to keep up with demand and maintain workmanship. This, combined with decreased government support and an oil price drop, resulted in problems for New Zealand's natural gas industry.

In 1985, the Labour Party, newly in power, believed it was time to reduce the incentives being inserted into the natural gas industry and allow the market to take over. Natural gas conversion loans were limited and required a cash deposit. Interest on the loans was increased from 10 percent to 17 percent. Only the incentives available for refuelling stations in new areas remained intact. Between June of 1985, when the reduction in incentives came into

effect, and December that same year, conversions dropped from 4200 a month to 240 a month.¹²

The collapse in world oil prices in 1986 again undercut the economic price advantage of converting to natural gas and lengthened the payback period on conversions. By 1988, the conversion rate had dropped to 100 per month.¹³

The slowdown in demand for conversions, combined with a government funded licensing program for natural gas mechanics, has allowed the conversion industry to improve its quality control and increase customer satisfaction. Although government incentives are still low in comparison with the industry startup years, private sector programs and initiatives continue to support the use of natural gas in vehicles and the export of natural gas technology for use in other countries.

C.1.3 Australia

Propane

In 1979, the Government of Australia began promoting the use of propane in response to a perceived oil shortage. Initially, government endorsement and incentives, which included exemption from the propane fuel excise tax, removal of the sales tax on conversion equipment, and qualifying commercial conversion costs for tax depreciation, generated a rapid rate of conversion. However, despite a readily available domestic supply source with annual exports of 1.5 million tonnes and a price, on a volume equivalent basis, of about half that of gasoline, technical, economic and institutional barriers constrained industry development to approximately 40,000 propane vehicles, 840 propane refuelling stations and a penetration of 1 to 2 percent into the gasoline fuel market.¹⁴

Compressed Natural Gas

Energy self-sufficiency is once again the driving force behind increased research and development to determine the potential of NGV in Australia. Within the past five years, this nation has dropped from being 90 percent self-sufficient in oil supply to less than 70 percent.¹⁵ The Bass Strait oil reserve, which supplied most of the domestic crude oil demand, is depleting rapidly and the Government is concerned at the prospects of high costs for imported oil. With twice the energy content in domestic gas reserves as is available from their oil reserves,

it is obvious why both natural gas and methanol are being considered to ease the need for high oil imports.

To date, NGV development and use has been concentrated in light-duty fleet vehicles owned and operated by natural gas companies. A number of pilot projects have been initiated, including four refuelling stations built by the Victoria Gas and Fuel Corp. to serve a number of fleets, including Melbourne Transit Authority buses. Perth, a remote market which is heavily dependent on imported oil, has city buses running on natural gas which are showing operating cost savings relative to diesel operations.¹⁶

Australia's research efforts to date indicate potential for natural gas use in the diesel bus and truck market in both the short and long term with light-duty penetration inhibited, at least in the short term, by the nation's natural gas distribution system which is concentrated in the southeastern portion of the country.

C.1.4 Italy

Compressed Natural Gas

Italy has experienced extensive use of natural gas, dating as far back as the early 1930s. High gasoline taxes and concern over fuel shortages were the driving forces behind the development and use of natural gas as a vehicle fuel.

Three hundred thousand natural gas vehicles, fuelled by approximately 230 natural gas stations, are currently in use. Because the fuelling infrastructure has been concentrated in northern and central Italy where there are relatively cheap natural gas supplies, most of the natural gas vehicles are dual-fuel. This has resulted in a delay in development of refuelling facilities elsewhere in the country.

The energy crisis of the 1970s bolstered the development of the natural gas industry which received even more stimulation with the rising concern for atmospheric pollution problems, particularly those pollutants related to diesel.

As is the case in many other areas, low natural gas prices, in part due to less onerous taxation, inspire interested motorists to convert to dual-fuelled vehicles. Continued development of refuelling stations will be necessary however, in order to eliminate the current lack of facilities in areas outside the central and northern districts. Added cylinder weight and space consumption, the slight decrease in

power, decreased driving range and increased refuelling time are still concerns. However, continued efforts are taking place to determine answers. Steel and fibre composite-structure tanks, which would provide a weight savings, as well as super absorbent high storage materials consisting of artificial zeolites or activated carbons, special clays and phosphates¹⁷ are examples of areas currently being studied in Italy.

Propane

In 1988, Italy had from 700,000 to 850,000 vehicles operating on propane¹⁸ with an automotive consumption of 1.1 million tonnes.¹⁹

C.2 Methanol and Ethanol

C.2.1 United States

Oil imports accounted for 24 percent of the United States trade deficit in the first half of 1987.²⁰ More than 200 billion barrels of oil were imported from Iraq and Kuwait in 1989. The United States is seeking secure sources of crude oil supplies, essential to its economic life, and will continue to strive toward this goal until it acquires access to adequate fuel resources at competitive costs.

The United States Department of Energy has recognized the potential for both ethanol and methanol as transportation fuels. American fossil fuel resources are rapidly declining and there is great concern with the pollution problems. With lead phased out of United States gasoline products, alcohols may be in higher demand as octane boosters. The United States has the necessary elements for a fuel-supply infrastructure, as both ethanol and methanol have been used extensively in their chemical industry. Also, low level blends of gasoline with ethanol and methanol have been sold in the marketplace.

Presently, ethanol accounts for almost all the alcohol being blended into unleaded gasoline in the United States and yet, relative to the total energy requirements in the transportation sector (9.8 million barrels per day (US) of crude oil equivalent), ethanol provides only 825 million gallons (US) annually or 0.3 percent of the transportation sector's energy demand.^{21,22} Nameplate U.S. fuel-ethanol plant capacity has been increasing but the number of operating plants has declined from peak times. Three out of five

fuel-ethanol plants, mainly small farm-scale operations, have shut down, primarily for economic reasons.²³

Currently, all the ethanol being used in the United States motor fuels is produced by the fermentation of sugars derived from biomass.²⁴ The major reason for using this process is that only fuel-alcohol produced from biomass is supported by tax exemptions in the United States. Ethanol blends at the federal level alone qualify for a 6 cents (US) per US gallon tax exemption, which is equivalent to 60 cents (US) per US gallon of pure ethanol.²⁵ This is equivalent to 20 cents (Cdn) per litre of ethanol. Many of the states also provide their own tax incentives, which range up to 14 cents per gallon or 4.6 cents (Cdn) per litre.²⁶ However, it appears that the high cost of ethanol is still restraining its further utilization in the U.S. market-place.

According to Bob Duneen, the Legislative Director for the Renewable Fuels Association in Washington, D.C., the United States fuel industry currently has an operational capacity of 1 billion gallons per year from more than 60 ethanol manufacturing facilities in 22 states. In 1988, 850 million gallons of ethanol were produced from 340 million bushels of surplus grain, increasing farm incomes by \$750 million and reducing federal farm program costs by \$600 million.²⁷ According to the National Corn Growers Association, ethanol production is projected to be 900 million gallons for 1990.

"Gasohol", a gasoline blend containing 10 percent ethanol, accounted for nearly 8 percent of total United States gasoline sales in 1988 and utilized 1.5 billion litres of ethanol. A further 15 to 20 percent of total U.S. gasoline sales are estimated to contain either MTBE or alcohols other than ethanol.²⁸

The United States is currently the largest producer of methanol in the world.²⁹ Although the partial oxidation of heavy and light crude oil fractions provides some of the United States methanol supply, most is produced through steam reforming of natural gas. The gasification of coal and biomass also hold potential for low cost methanol production, but at the present time have not been found competitive.

In 1988, methanol provided 0.09 percent, or 280 million gallons (US), of the transportation sector's annual energy demand. About 95 percent of this methanol is used to make MTBE which in turn provides about 1.2 billion gallons (US) per year of automotive fuel in the form of gasoline blends.³⁰

Approval must be sought from the United States EPA for changes in composition to unleaded gasoline, since it is the responsibility of this agency to determine whether or not the additives (e.g., oxygenates) will result in unsatisfactory exhaust emissions from vehicles designed for unleaded gasolines. The EPA has approved several oxygenated blends, including blends containing up to 10 percent ethanol and up to 11 percent MTBE (in September of 1989 the EPA conditionally granted a waiver for a fuel containing 15 percent MTBE to Sun Refining and Marketing Company).

In addition to the increasing demand for methanol in the production of MTBE, the major thrust for greater methanol use came as a result of President Bush's proposed amendments to the Clean Air Act as well as similar proposals from the United States Congress. The final bill, which is estimated to cost \$25 billion a year, requires that nitrogen oxide and hydrocarbon emissions from automobiles be reduced 60 and 40 percent respectively, beginning with 1994 model cars. Another requirement is that fleets in the twenty-five most polluted areas switch to alternative fuels.

The bill authorizes an alternative fuel program for California under which 150,000 alternative fuel vehicles must be sold annually to the state beginning with 1996 models, increasing to 300,000 vehicles in the 1999 model year. Also, areas not complying with ozone standards must determine ways to do so.³¹

C.2.2 Brazil

Brazil is the world's largest producer of ethanol. The oil crises of the 1970s prompted the Brazilian government to recognize the importance of becoming less dependent on expensive foreign oil. As a result, Brazil turned to the production of ethanol to reduce their import bill and to ensure themselves of a more stable domestic fuel supply. Another pertinent factor was the need to assure Brazilian farmers of higher prices for their sugar cane. The emergence of an ethanol industry produced other benefits for the Brazilian economy as well; employment opportunities were created in the new ethanol industry and were rejuvenated in the previously declining agricultural industry.

Brazil's production of alcohol fuel was approximately 3 billion gallons (US) in 1986.³² Government incentives ensured that in 1986, virtually all gasoline sold in Brazil was an "E20" blend. In 1988, more than 90 percent of all new vehicles sold in Brazil were powered by fuel-ethanol engines and one-third of the vehicles operating ran on

96 percent ethanol and 4 percent water. A small 1 to 2 litre tank of gasoline is necessary for starting these vehicles, especially for temperatures of 15°C or less. Fuel ethanol has also been used as a diesel fuel in Brazil; however, additives are required to improve the ignition characteristics.³³

Brazil's PROALCOOL program has had and continues to have its problems. The first two phases of the program involved expanding ethanol production and promoting all-ethanol vehicles. Fixing sugar prices and quotas by the National Institute for Sugar and Alcohol on a cost basis, introducing producer credit subsidies which paid up to 75 percent of investment, and government assurance that sugar mills/distilleries would receive 6 percent return on their investment as long as they produced ethanol rather than exported their sugar, ensured the success of phase one.

Phase two, prompted by the 1979 oil price rise and the impact on the country's foreign debt, called for a massive switch to dedicated ethanol vehicles with the aim of reaching 50 percent of vehicle sales by 1985. Lower purchase taxes, lower registration fees, smaller down payments, tripled repayment periods, and lower fuel costs encouraged customers to buy the new vehicles. Problems occurred when initial sales of ethanol cars and retrofits were so high that Brazilian manufacturers implemented only the minimum modifications required for all ethanol vehicles and authorized mechanics began offering inferior conversions at lower prices. The result was less than optimum efficiency from the cars and consumer dissatisfaction.

Other problems also began emerging. Price controls made it more profitable for some producers to export anhydrous alcohol rather than to supply ethanol (hydrous alcohol) to the domestic market. This resulted in insufficient supplies to meet the automotive demand. Also, when world sugar prices were predicted to rise and the government responded by increasing ethanol pump prices from a low of 40 percent of gasoline prices towards the 65 percent limit and suspending credit subsidies for distillers, sales of ethanol vehicles dropped sharply from 73 percent of all auto sales in December 1980 to 9 percent in July 1981. These problems revealed the program's dependence on extensive government intervention in the market. They also indicate just how quickly consumers react to a change in commitment and prices.

Brazil's massive foreign debt continues to rise, petroleum supplies remain uncertain, and world sugar prices are rising. Higher prices on the world sugar market have prompted Brazilian sugar

producers to sell into that market rather than make alcohol. This has produced an ethanol fuel shortage in Brazil which is forcing the country to import large quantities of ethanol. Both methanol and MTBE have been considered as substitutes for fuel ethanol. Considerations given to using a blend of 33 percent methanol, 60 percent ethanol and 7 percent gasoline in the ethanol fuelled vehicles and a blend of 10 percent methanol, 12 percent ethanol and 78 percent gasoline for all other cars met with protests from environmentalists as well as gas station attendants concerned with using a product which they felt may be harmful to the atmosphere as well as to those who handle it. In December 1989, a Brazilian judge banned further methanol imports until an environmental impact study was completed. This may be lifted in the near future.³⁴

Brazil's alternative to ethanol production would be increasing domestic petroleum exploration and exporting sugar. However, domestic oil exploration is expensive and exporting sugar is likely to result in depressing even further the world market sugar price.³⁵

C.2.3 West Germany and Austria

In 1985, 80 percent of all gasoline sold in West Germany contained between 2 and 3 percent methanol with tertiary butyl alcohol (TBA) as a cosolvent.³⁶ West Germany must rely on imported energy sources for much of its transportation requirements. Spark-ignition systems and diesel engines capable of using fuel-ethanol and fuel-methanol blends have been developed by Volkswagen and Daimler-Benz. Fuel-methanol engines, developed by Deutz and Mann, are currently being tested in heavy-duty trucks and buses. Porsche is also contributing to the advancement of oxygenated fuels with their experimental vehicles which can operate using either gasoline or fuel-methanol exclusively.

In Austria, blends of 90 percent domestic gasoline with 3 percent methanol, 2 percent TBA and up to 5 percent MTBE are being marketed.³⁷ The blending of the oxygenated fuel occurs at Austria's single, state-owned refinery. The remaining demand for gasoline in Austria is met by supplies from West Germany, which also contain methanol and TBA, and from Italy.

C.2.4 Japan

Japan has extensively addressed the use of "neat alcohol" as well as alcohol blended with both gasoline and diesel fuel. Toyota,

Honda, and Nissan have all done comprehensive research and experimentation with methanol as a fuel. Both Toyota and Nissan have agreed to share data with the United States EPA on emission characteristics of methanol engines.³⁸

Footnotes

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*Appendix D****THE OEM SENSITIVITIES***



Appendix D

THE OEM SENSITIVITIES

D.1 Equating the Cost of Alternatives to a Clean Environment

Clean burning alternative fuels provide an option to alleviate current air pollution concerns. Improving air quality through clean fuels will require changes to the market environment which provide economic reassurances to all the stakeholders and encourage the provision of adequate supplies of the fuels and low emission vehicles. Where economic incentives are determined to be necessary, it may be appropriate to link the level of the incentive directly to the fuel's environmental benefits.

It is difficult, however, to calculate the environmental value of these fuels or the monetary cost to society of substituting cleaner burning fuels for a portion of the fossil fuels currently being marketed. Many of the variables that would go into the calculation (i.e., fuel production costs, refuelling station investments, fuel efficiencies) are in constant flux and affected by exogeneous variables such as; feedstock quality, feedstock costs, labour costs, interest rates, and inflation, which are constantly changing. Following is an example of how the cost of reducing emissions by one tonne might be calculated, using the case where methanol is substituted for diesel fuel in urban buses.

Methanol Fuelled Urban Buses Costs of Emission Reductions

Per bus:

Annual diesel consumption	26 500 L
Methanol replacement	54 166 L
Conversion cost	\$12,000
Annual cost assuming sixteen year life	\$1,462
Production cost of displaced fuel	\$8,520
Production cost of methanol displacement	\$6,879
Station costs per bus	\$8,333
Annual cost per bus assuming a sixteen year station life	\$1,045

Combustion emissions reductions per bus per year:

$$\begin{aligned} \text{HC} & (7 \text{ g/mile}) + (1.6 \times 50\,000 \text{ km}) = 42.81 \text{ kg} \\ \text{CO} & (21.72 \text{ g/mile}) + (1.6 \times 50\,000 \text{ km}) = 678.75 \text{ kg} \\ \text{NO}_x & (20.56 \text{ g/mile}) + (1.6 \times 50\,000 \text{ km}) = 642.5 \text{ kg} \\ \text{Particulates} & (4.761 \text{ g/mile}) + (1.6 \times 50\,000 \text{ km}) = 148.78 \text{ kg} \end{aligned}$$

Production emissions reductions per bus per year:

$$\begin{aligned} & \text{Diesel Production Emissions less Methanol Production Emissions} \\ \text{HC} & 0.88245 \text{ kg} - 0.498 \text{ kg} = 0.384 \text{ kg} \\ \text{CO} & 0.0265 \text{ kg} - 40.2 \text{ kg} = -40.17 \text{ kg} \\ \text{NO}_x & 0.3445 \text{ kg} - 52.57 \text{ kg} = -52.23 \text{ kg} \\ \text{PM} & = 0 \end{aligned}$$

Total emissions reductions per bus per year:

$$\begin{aligned} \text{HC} & = 43.19 \text{ kg} \\ \text{CO} & = 638.6 \text{ kg} \\ \text{NO}_x & = 590.3 \text{ kg} \\ \text{PM} & = 148.78 \text{ kg} \end{aligned}$$

NOTE: Emissions in grams/mile were determined by averaging data provided from a number of sources. Yearly costs and benefits of bus conversions:

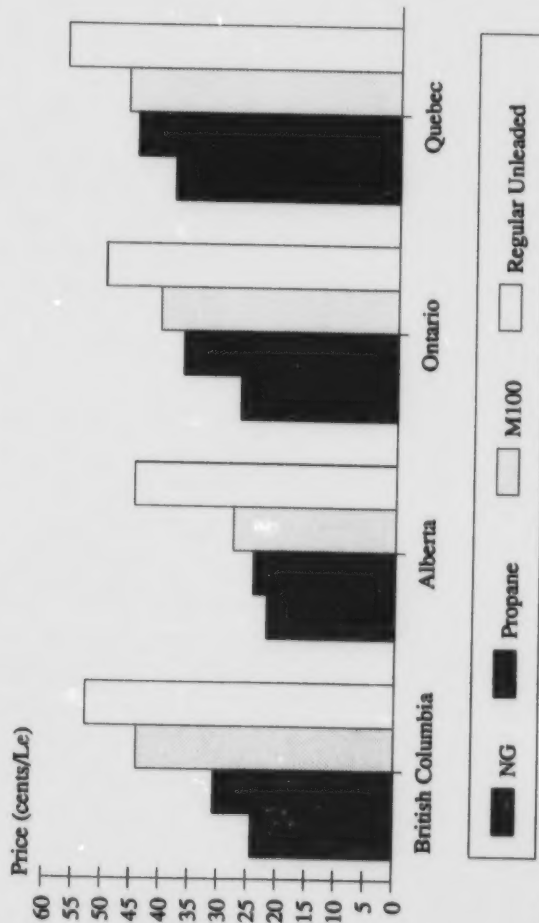
Conversion costs	\$1,462
Station costs	\$1,045
Differential production costs	<u>\$-1,641</u>
	\$ 866

The cost per tonne of emissions reduction:

$$\begin{aligned} \text{HC} & = \$20,051 \\ \text{CO} & = \$1,356 \\ \text{NO}_x & = \$1,467 \\ \text{Particulates} & = \$5,821 \end{aligned}$$

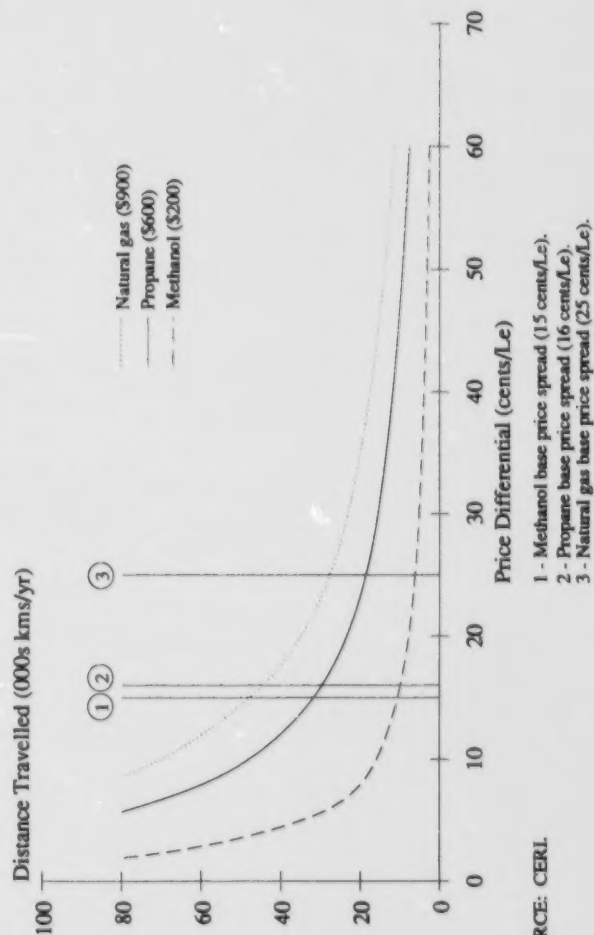
Similar calculations can be performed for all the clean fuels. However, as noted earlier, some of the alternatives have more emissions data available than others, making it currently rather difficult to determine and compare these costs. It is important that any offsetting pollution increases (i.e., increased emissions of NO_x in some cases) be included in the analysis where applicable.

Figure D.1
Gasoline Equivalent Prices
1990



SOURCES: CANMET, CGA, EMR Canada, PGAC.

Figure D.2
OEM Case: Light/Medium Vehicles
One-Year Payback



SOURCE: CERL.

Figure D.3
OEM Case: Heavy Vehicles
One-Year Payback

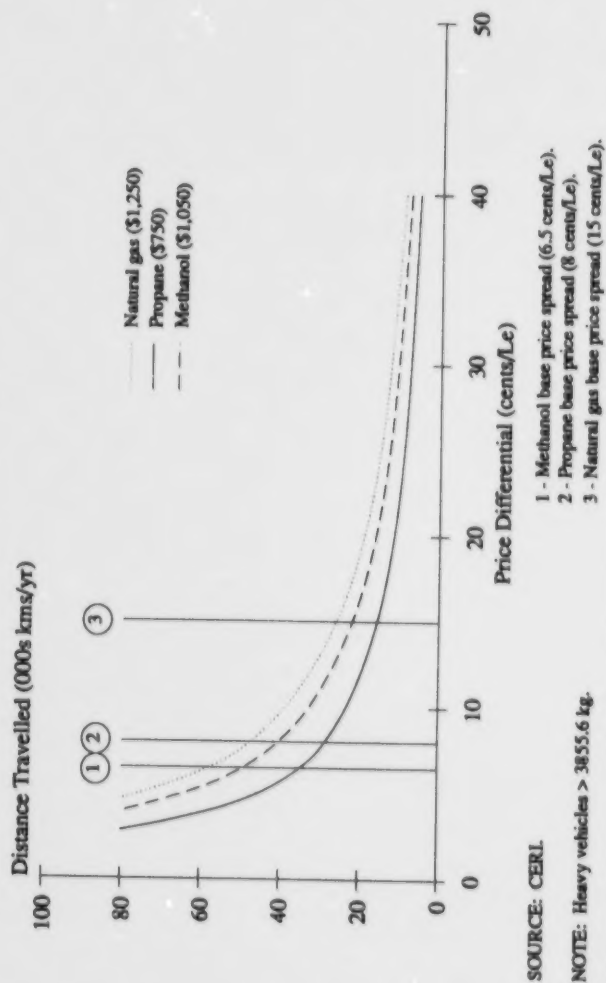


Figure D.4
OEM Case: Heavy Vehicles
Five-Year Payback

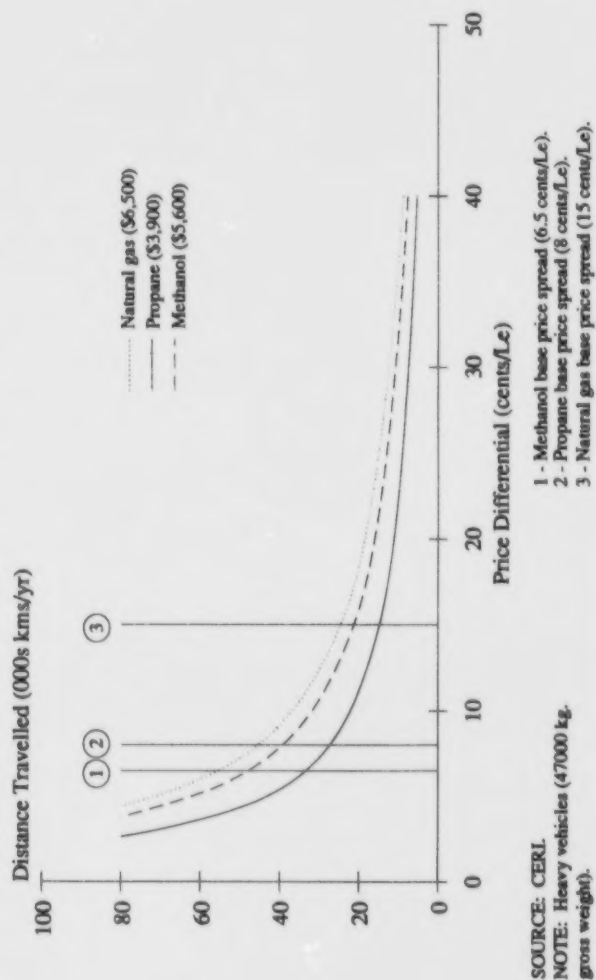


Figure D.5
OEM Case: Buses
Five-Year Payback

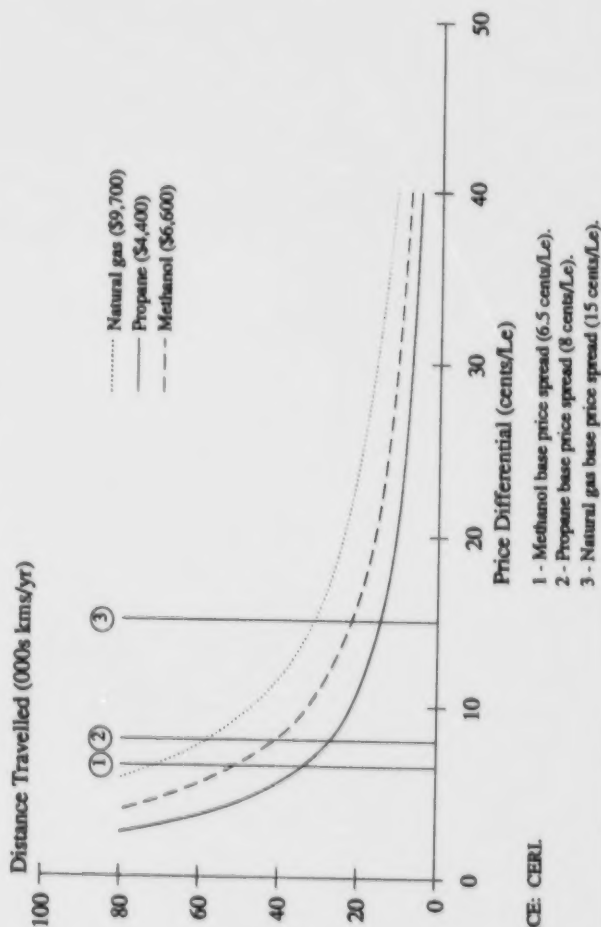


TABLE D.1
PROVINCIAL FUEL PRICES, TAXES, AND INCENTIVES

Province	Consumption Taxes ^a (¢/L)			Retail Price (¢/gasoline litre equivalent)					Incentives and Taxes
	Propane	Regular Unleaded	Diesel	Diesel ^b	Regular			Methanol ^c	
					Unleaded ^b	CNG ^c	Propane ^d		
Quebec	8.25	14.40	12.45	52.8	57.1	38.47	44.92	46.6	8 percent sales tax on vehicles and conversion kits.
Ontario	4.3	11.3	10.9	48.8	50.1	26.85	36.69	40.7	No provincial sales tax on conversion kits, 6 percent sales tax on gasoline vehicles, sales tax rebate of up to \$1,000 for CNG and \$750 for LPG conversions.
Manitoba	5.7	9.0	9.9	45.1	46.5	N/A	33.60	N/A	No road tax on NGV.
Saskatchewan	7.0	10.0	10.0	46.5	49.3	N/A	33.72	N/A	No road tax on NGV.
Alberta	5.0	7.0	7.0	37.9	44.8	22.02	24.32	27.92	No road tax on NGV.
B.C.	0.0	9.83	10.27	44.5	52.9	24.28	30.81	44.11	No provincial sales tax on conversion kits. Provides an additional \$200 per vehicle converted.
Federal Taxes +									
Sales	3.74	3.85	2.86						
Excise	8.5	8.5	4.0						

SOURCES: Price Waterhouse, Energy, Mines and Resources Canada, Canadian Gas Association.

^aEnergy, Mines and Resources Canada, Consumption Taxes on Petroleum Products, September 1, 1990.

^bEnergy, Mines and Resources Canada, Energy Statistics Handbook, Average of 1989 values.

^cCanadian Gas Association, based on NG density of 0.723 kg/m³, 10 percent efficiency gain for NGV versus gasoline.

^dPropane, EMR oil and gas branch. Based on Btu content and a 10 percent efficiency gain for propane versus gasoline.

^eBased on CANMET Projections for M90, and EMR regular unleaded prices, and a 20 percent efficiency gain for methanol versus gasoline.

Appendix E
**NATURAL GAS CONVERSION
SCENARIOS**



Appendix E

NATURAL GAS CONVERSION SCENARIOS

Discount Rate: 10 percent

Fuel Consumption:	Light/Medium Vehicles	125 Le per 1000 km
	Heavy Vehicles ¹	350 Le per 1000 km
	Heavy Vehicles ²	460 Le per 1000 km
	Buses	530 Le per 1000 km

Annual Distance Travelled, Base Case:

Light/Medium Vehicles, Personal:	20 000 km
Light/Medium Vehicles, Commercial:	up to 75 000 km
Heavy Vehicles:	40 000 km
Buses:	50 000 km

Conversion Costs (\$):	Optimistic Case	Base Case	Pessimistic Case	OEM Case
Light/Medium Vehicles	2,200	2,800	3,200	900
Heavy Vehicles ¹	3,200	3,700	4,200	1,250
Heavy Vehicles ²	20,000	22,500	25,000	6,500
Buses	20,000	35,000	50,000	9,700

Base Case Price Differentials: 25 cents per litre gasoline equivalent
15 cents per litre diesel equivalent

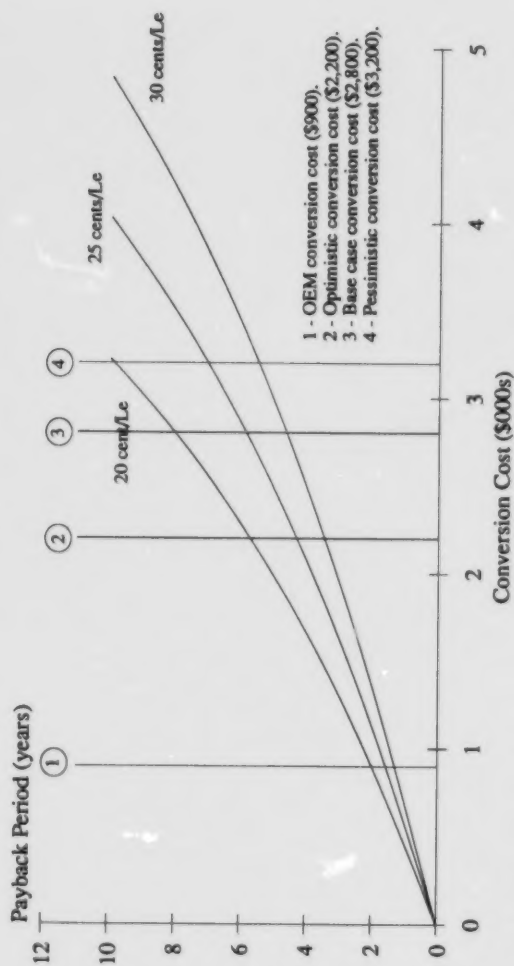
Station Costs: \$250,000. Lifetime: fifteen years. If each station serves 190 vehicles (based on current NGV market statistics), each consuming 2500 Le per year (based on 125 L/1000 km times 20 000 km), the station must receive 6.6¢/Le in profit to recover the initial \$250,000 investment.

NOTE: Natural gas was assumed to replace gasoline in light/medium vehicles and diesel fuel in the heavy vehicles and buses.

¹Vehicles weighing > 3855.6 kg.

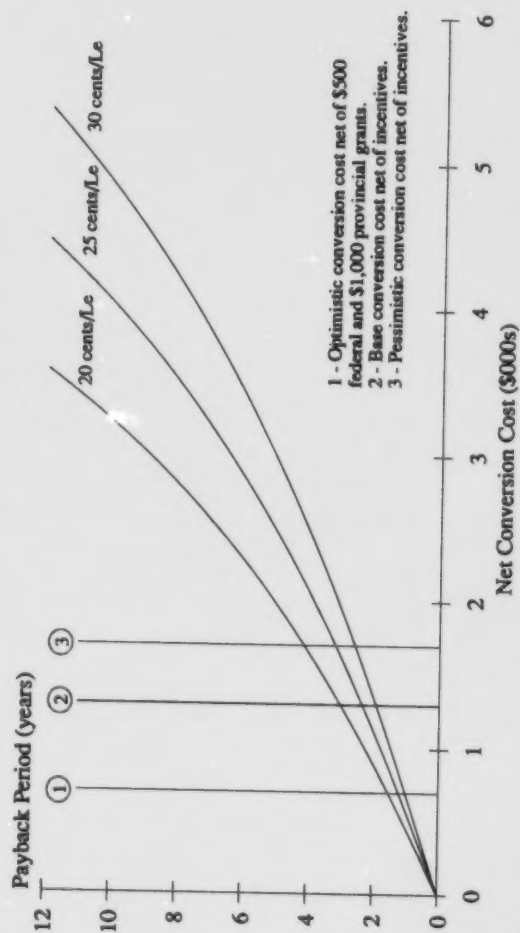
²Vehicles weighing = 47 000 kg.

Figure E.1
Payback Based on Price Differential and
Conversion Cost for L/M Vehicles



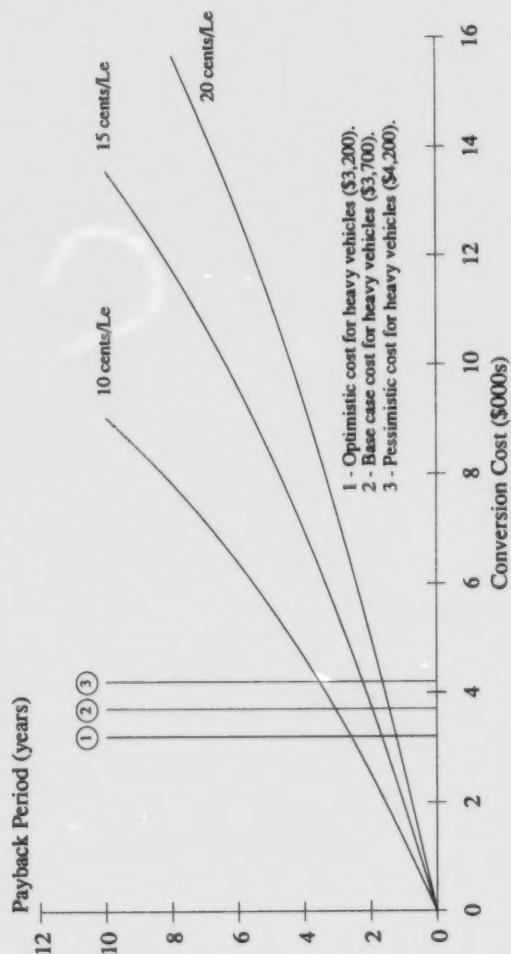
SOURCE: CERL

Figure E.2
Payback Based on Price Differential and
L/M Conversion Cost Net of Incentives



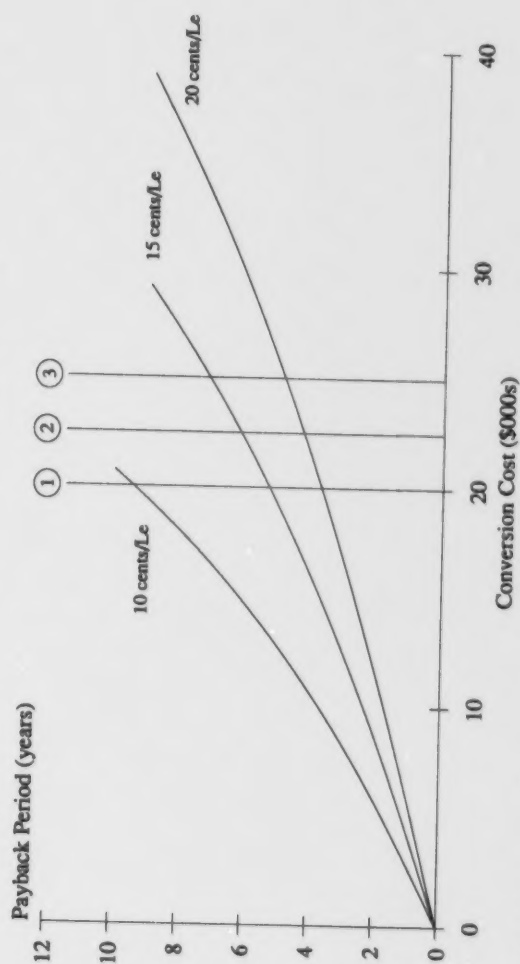
SOURCE: CERL

Figure E.3
Payback Based on Price Differential and
Conversion Cost for Heavy Vehicles



SOURCE: CERL.
 NOTE: Heavy vehicles weighing over
 3855.6 kg.

Figure E.4
Payback Based on Price Differential and
Conversion Cost for Heavy Vehicles

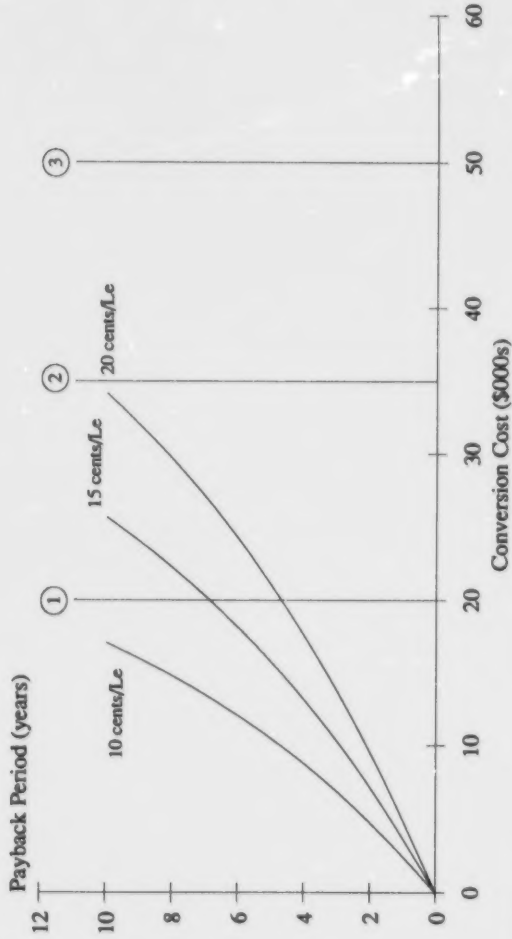


SOURCE: CERI.

NOTE: Heavy vehicles weighing approximately 47,000 kg.

- 1 - Optimistic cost for heavy vehicles (\$20,000).
- 2 - Base case cost for heavy vehicles (\$22,500).
- 3 - Pessimistic cost for heavy vehicles (\$25,000).

Figure E.5
Payback Based on Price Differential and
Conversion Cost for Urban Buses



SOURCE: CERL

- 1 - Optimistic conversion costs (\$20,000).
- 2 - Base case conversion costs (\$35,000).
- 3 - Pessimistic conversion costs (\$50,000).

Figure E.6
Payback Based on Distance Travelled and
Price Spread for L/M Vehicles

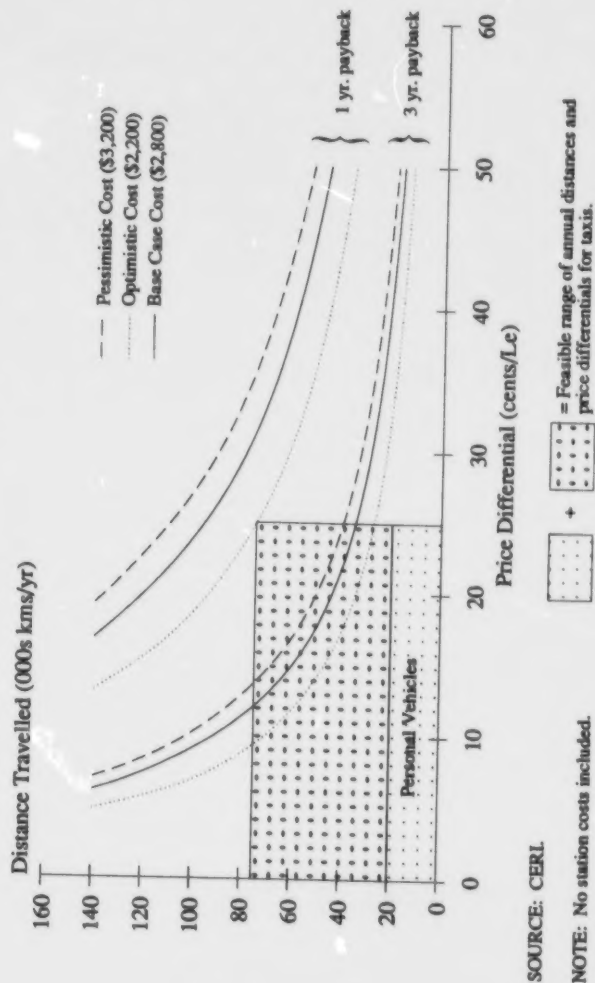


Figure E.7
Payback Based on Distance Travelled and
Price Spread for Heavy Vehicles

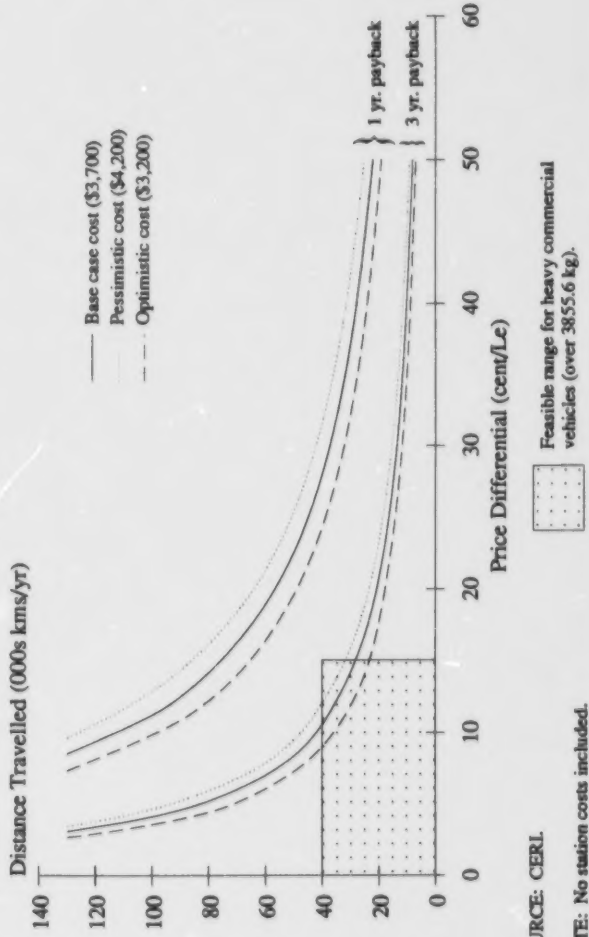


Figure E.8
Payback Based on Distance Travelled and
Price Spread for Heavy Vehicles

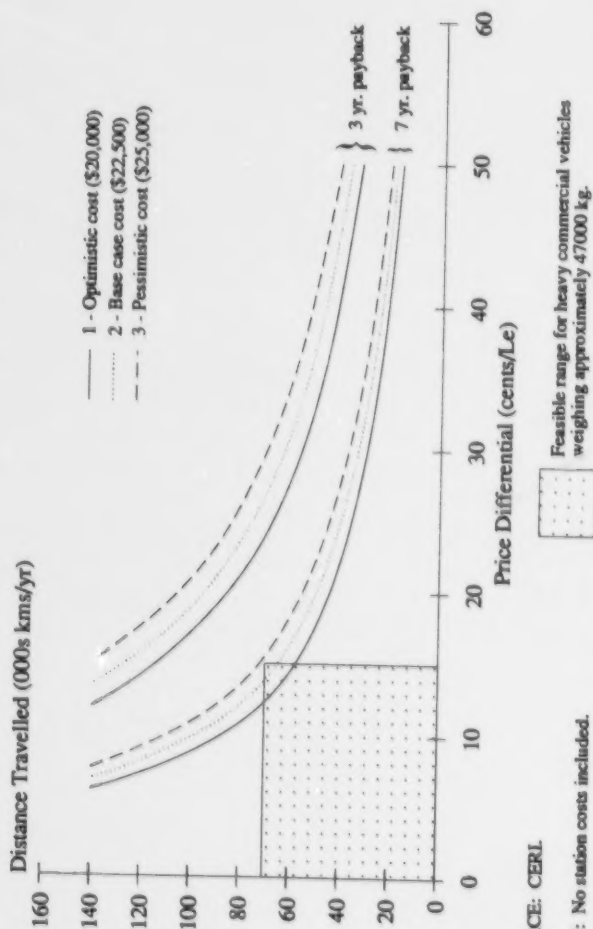
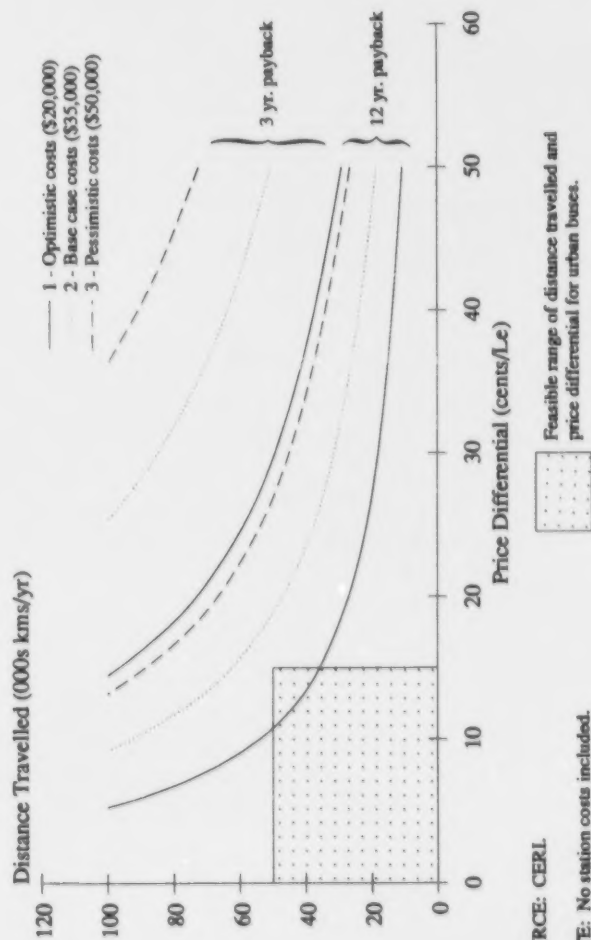


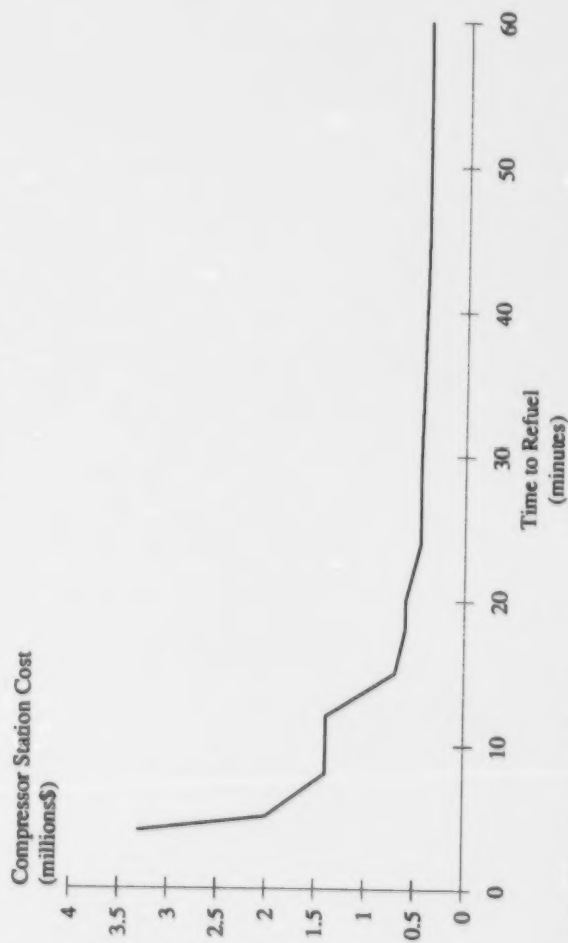
Figure E.9
Payback Based on Distance Travelled and
Price Spread for Urban Buses



SOURCE: CERL

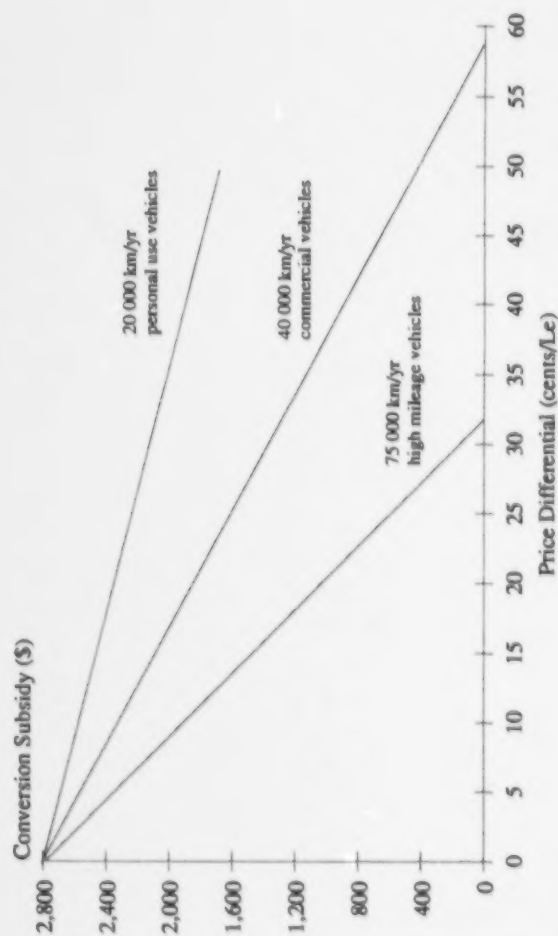
NOTE: No station costs included.

Figure E.10
Natural Gas Powered Vehicles
Refuelling Time vs. Cost



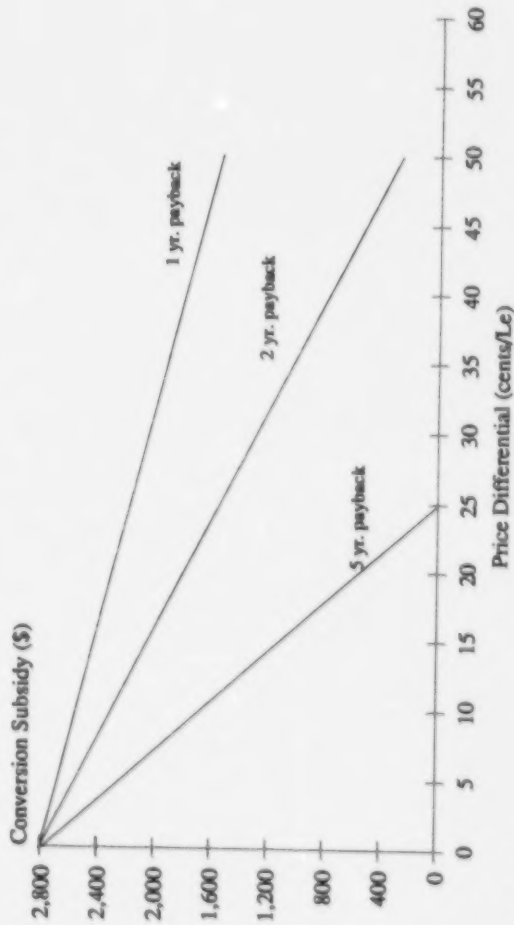
SOURCE: Ontario Bus Industries Inc.

Figure E.11
Light/Medium NGV Conversion Subsidy
vs. Price Incentive: One-Year Payback



SOURCE: CERL.

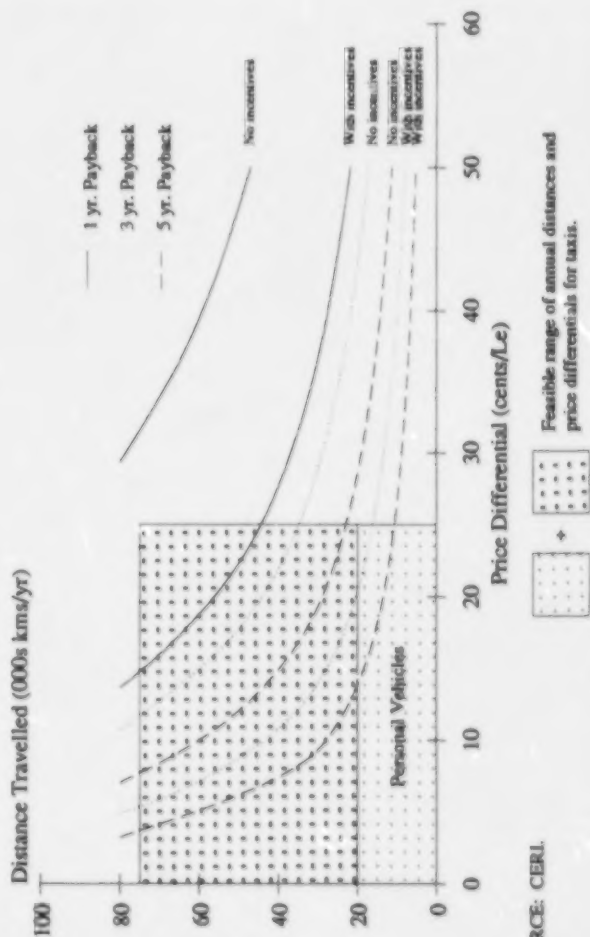
Figure E.12
Light/Medium NGV Conversion
Required Subsidy vs. Price Spread



SOURCE: CERL

NOTE: Annual distance travelled,
 20 000 kilometres.

Figure E.13
Effect of Incentives on
Payback Period



SOURCE: CERL.

Appendix F

**PROPANE CONVERSION
SCENARIOS**



Appendix F

PROPANE CONVERSION SCENARIOS

Discount Rate: 10 percent

Fuel Consumption:	Light/Medium Vehicles	125 Le per 1000 km
	Heavy Vehicles ¹	350 Le per 1000 km
	Heavy Vehicles ²	460 Le per 1000 km
	Buses	530 Le per 1000 km

Annual Distance Travelled, Base Case:

Light/Medium Vehicles, Personal:	20 000 km
Light/Medium Vehicles, Commercial:	up to 75 000 km
Heavy Vehicles:	40 000 km
Buses:	50 000 km

Conversion Costs (\$):	Optimistic Case	Base Case	Pessimistic Case	OEM Case
Light/Medium Vehicles	1,400	1,800	2,200	600
Heavy Vehicles ¹	1,800	2,200	2,600	750
Heavy Vehicles ²	9,000	12,000	15,000	3,900
Buses	10,000	13,500	17,000	4,400

Base Case Price Differentials: 16 cents per litre gasoline equivalent
8 cents per litre diesel equivalent

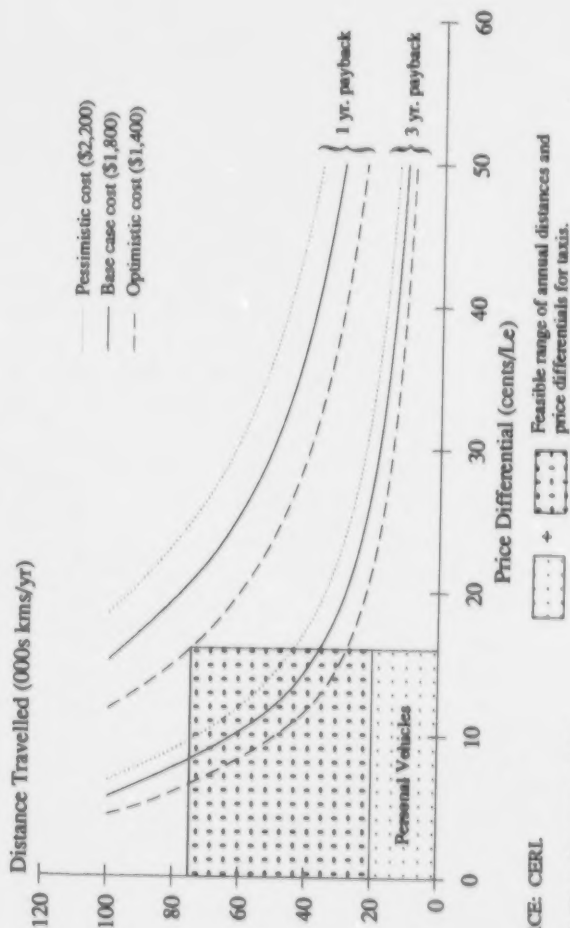
Station Costs: \$40,000. Thirty vehicles per station each consuming 2500 Le/yr, with a fifteen year station life. This requires a 6.74 cents/Le profit to recover the start-up cost of \$40,000.

NOTE: Propane was assumed to replace gasoline in light/medium vehicles and diesel fuel in the heavy vehicles and buses.

¹Vehicles weighing > 3855.6 kg.

²Vehicles weighing = 47 000 kg.

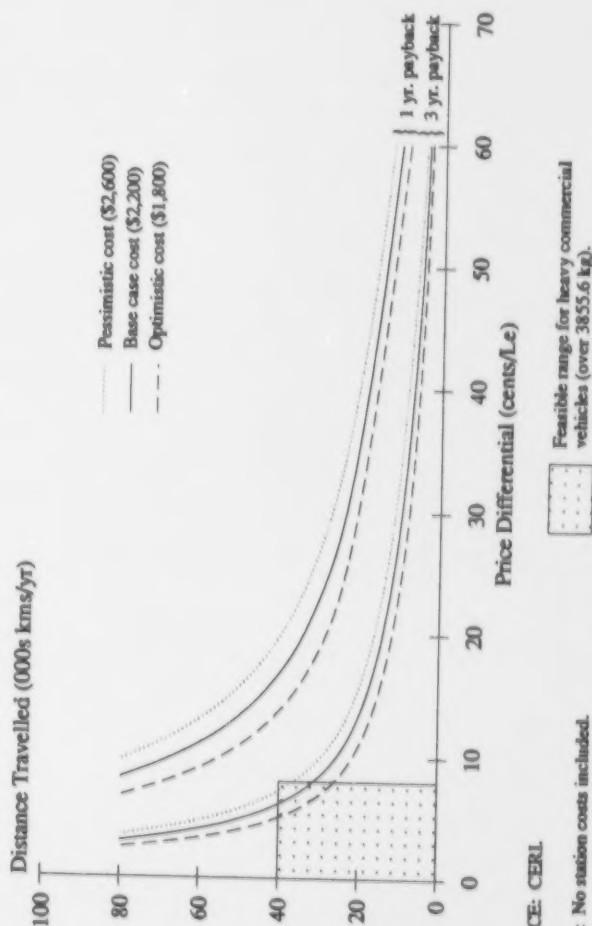
Figure F.1
Payback Based on Distance Travelled and
Price Spread for L/M Vehicles



SOURCE: CERL

NOTE: No station costs included.

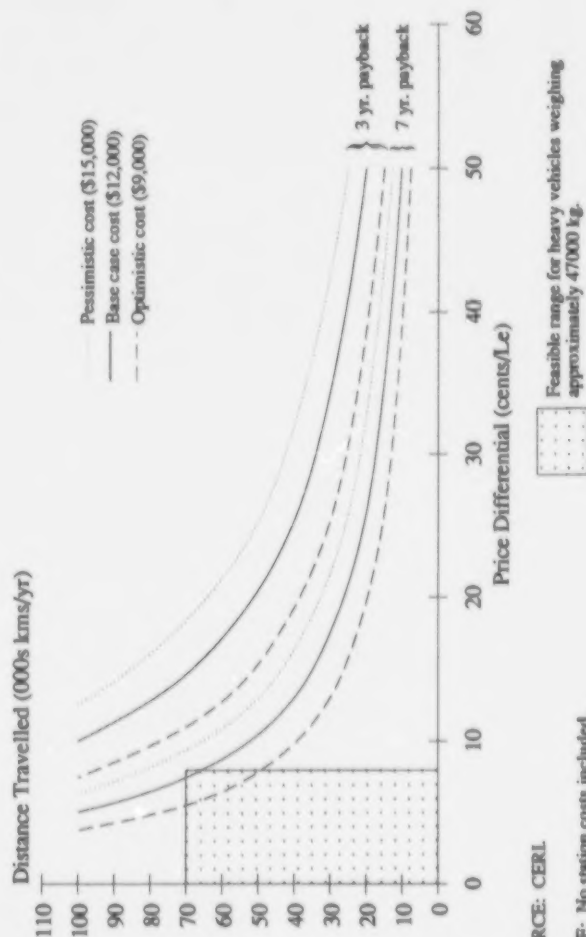
Figure F.2
Payback Based on Distance Travelled and
Price Spread for Heavy Vehicles



SOURCE: CERL

NOTE: No station costs included.

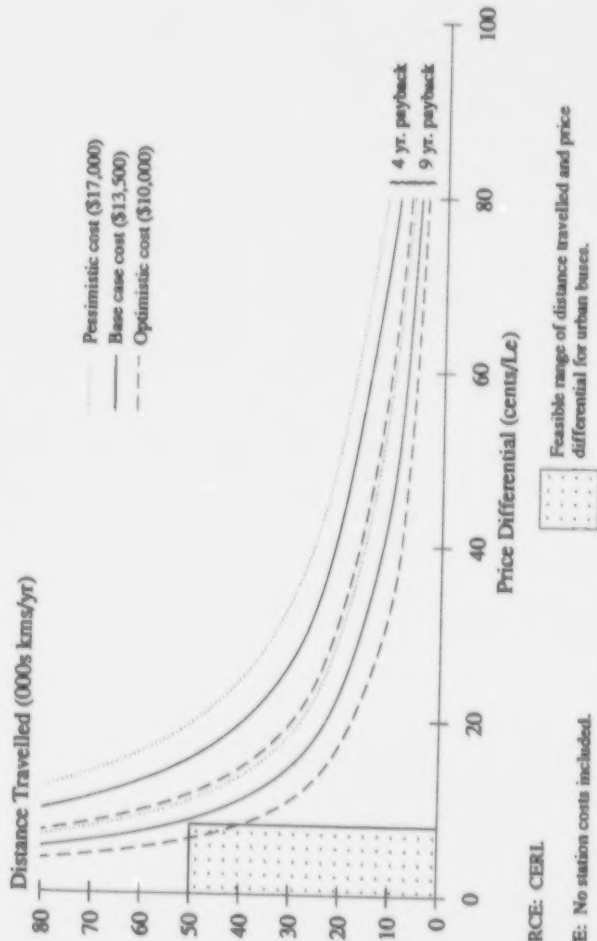
Figure F.3
Payback Based on Distance Travelled and
Price Spread for Heavy Vehicles



SOURCE: CERL

NOTE: No station costs included.

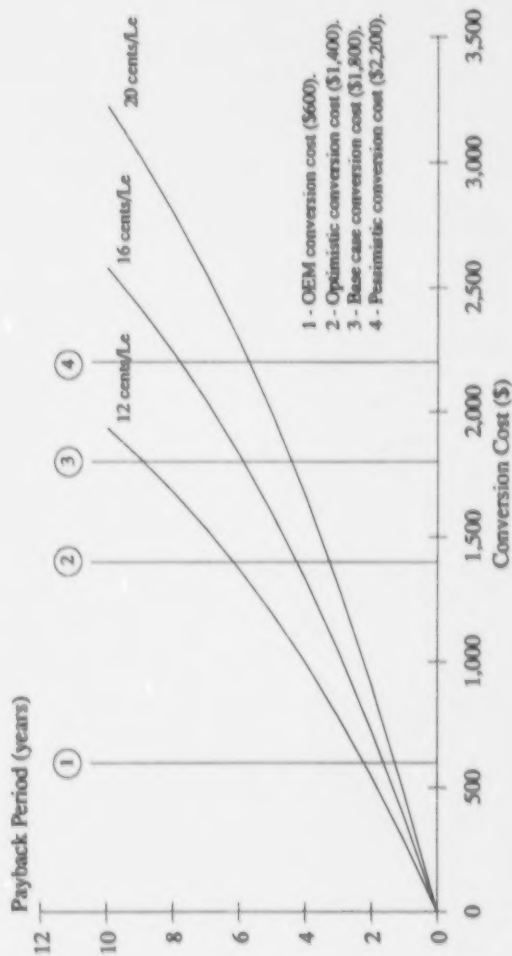
Figure F.4
Payback Based on Distance Travelled and
Price Spread for Urban Buses



SOURCE: CERL

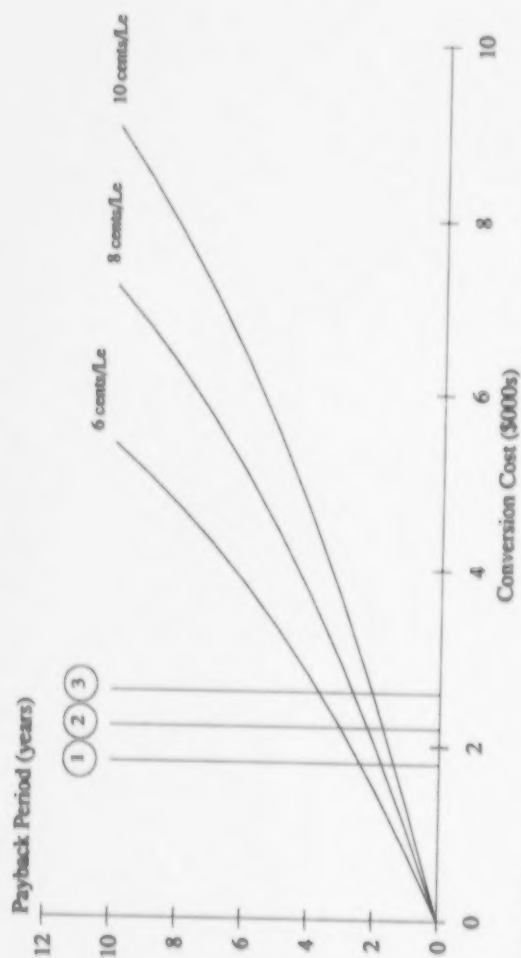
NOTE: No station costs included.

Figure F.5
Payback Based on Price Differential and
Conversion Cost for L/M Vehicles



SOURCE: CERL

Figure F.6
Payback Based on Price Differential and
Conversion Cost for Heavy Vehicles



SOURCE: CERL

NOTE: Heavy vehicles weighing over
3855.6 kg.

Figure F.7
Payback Based on Price Differential and
Conversion Cost for Heavy Vehicles

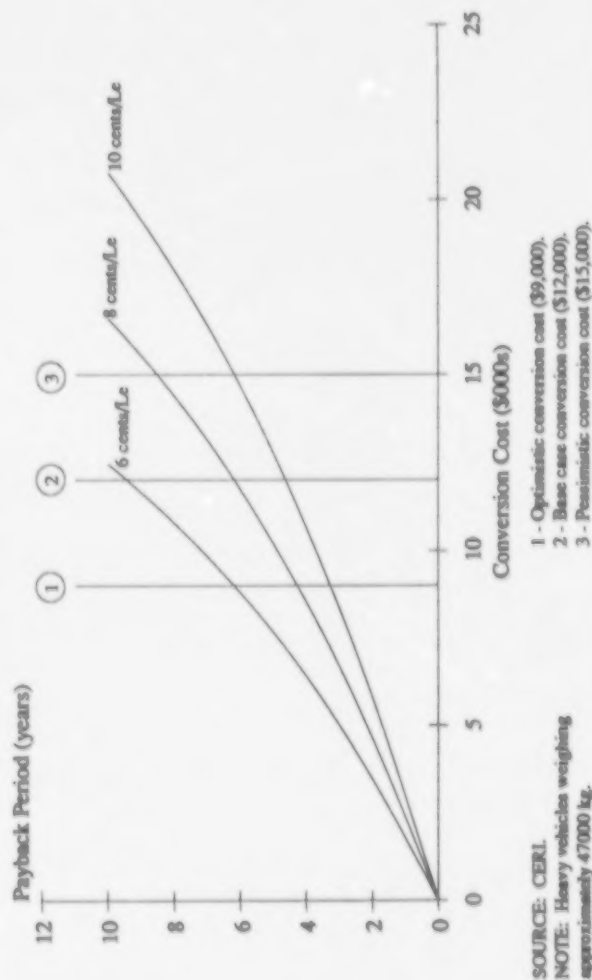


Figure F.8
Payback Based on Price Differential and
Conversion Cost for Urban Buses

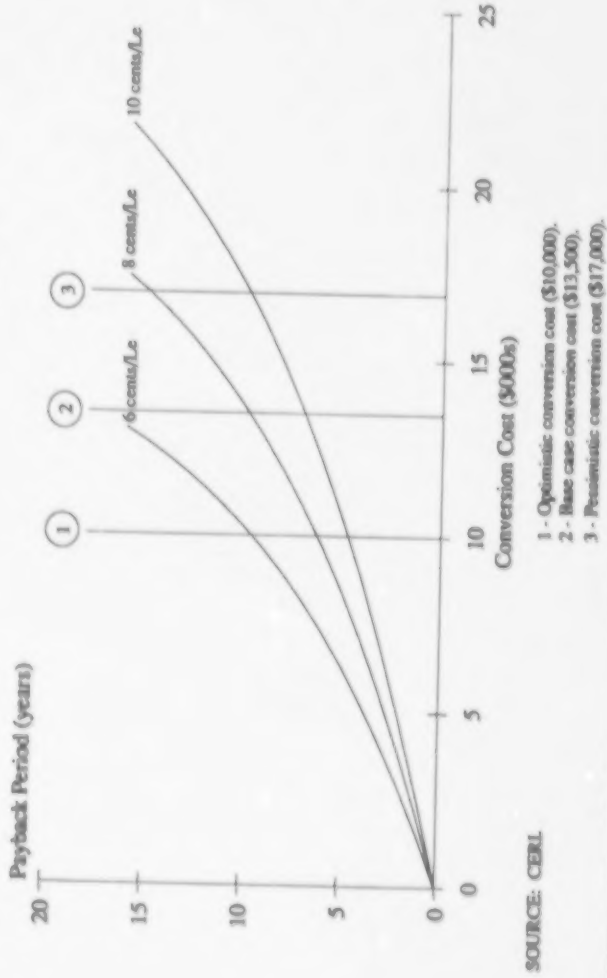
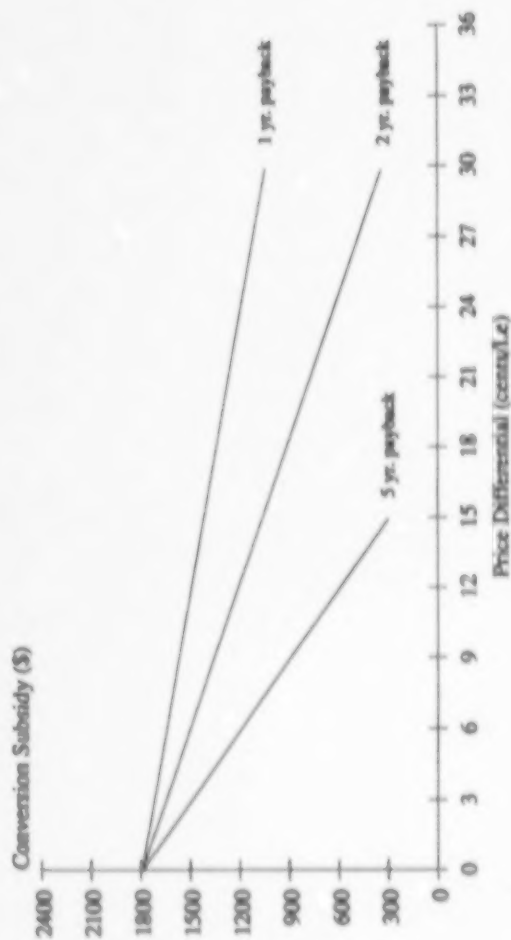


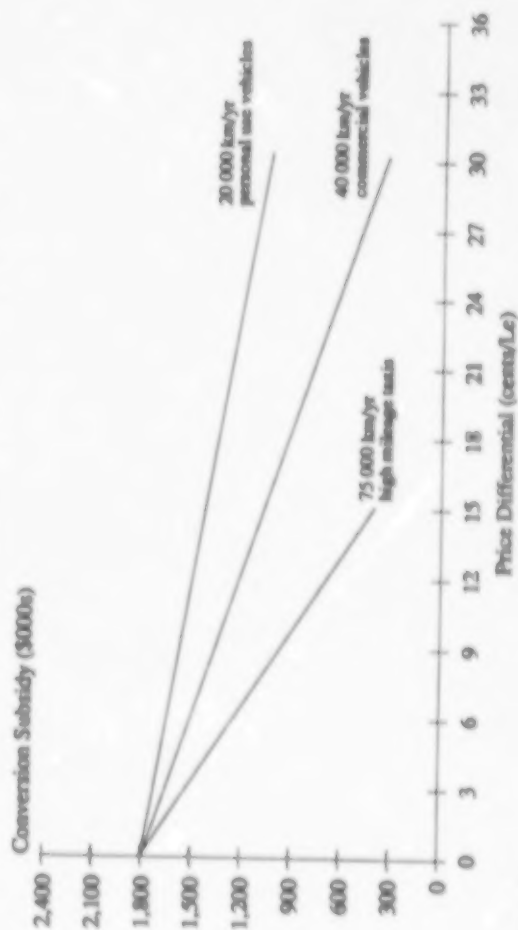
Figure F.9
Light/Medium Propane Conversion
Required Subsidy vs. Price Spread



SOURCE: CEBL

NOTE: Personal Use Vehicles: Required subsidy and price differential to achieve payback.

Figure F.10
Light/Medium Propane Conversion Subsidy
vs. Price Incentive: One-Year Payback



SOURCE: CERL

NOTE: Required Subsidy and price differential to achieve payback.



Appendix G
**METHANOL CONVERSION
SCENARIOS**



Appendix G

METHANOL CONVERSION SCENARIOS

Discount Rate: 10 percent

Fuel Consumption:	Light/Medium Vehicles	125 Le per 1000 km
	Heavy Vehicles ¹	350 Le per 1000 km
	Heavy Vehicles ²	460 Le per 1000 km
	Buses	530 Le per 1000 km

Annual Distance Travelled, Base Case:

Light/Medium Vehicles, Personal:	20 000 km
Light/Medium Vehicles, Commercial:	up to 75 000 km
Heavy Vehicles:	40 000 km
Buses:	50 000 km

Conversion Costs (\$):	Optimistic Case	Base Case	Pessimistic Case	OEM Case
Light/Medium Vehicles	500	1,000	2,000	200
Heavy Vehicles ¹	2,200	2,700	3,200	1,050
Heavy Vehicles ²	6,000	9,000	12,000	5,600
Buses	12,000	20,000	28,000	6,600

Base Case Price Differentials: 15 cents per litre gasoline equivalent
6.5 cents per litre diesel equivalent

Station Costs: \$150,000. Assumes each station serves 190 vehicles, each consuming 2500 Le per year.

NOTE: Methanol was assumed to replace gasoline in light/medium vehicles and diesel fuel in heavy vehicles and buses.

¹Vehicles weighing > 3855.6 kg.

²Vehicles weighing = 47 000 kg.

Figure G.1
Payback Based on Distance Travelled and
Price Spread for L/M Vehicles

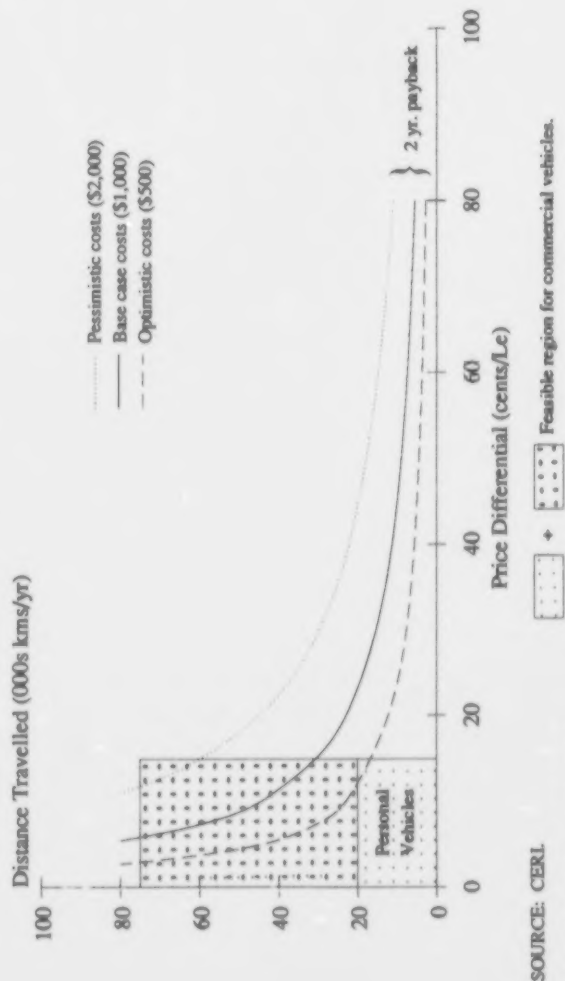
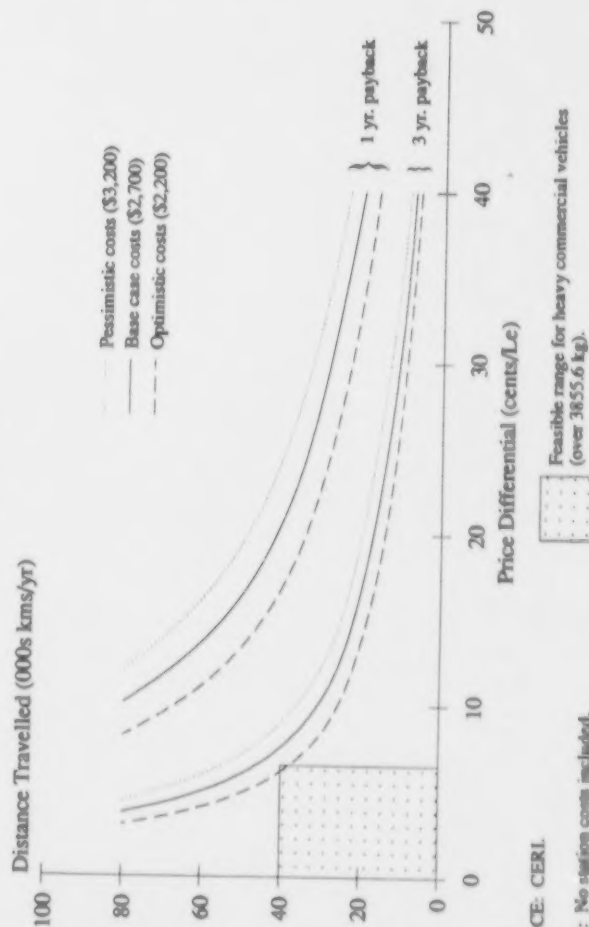


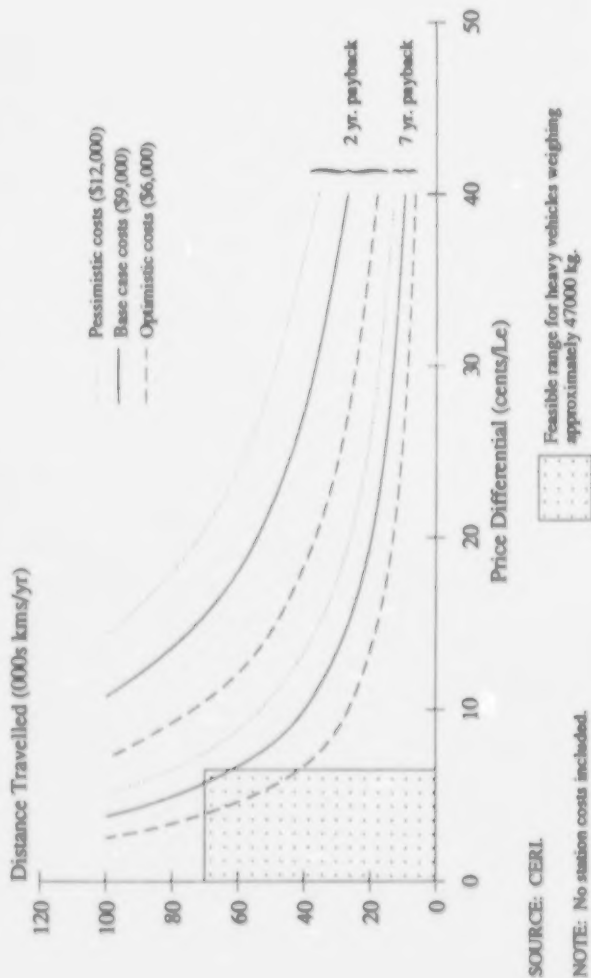
Figure G.2
Payback Based on Distance Travelled and
Price Spread for Heavy Vehicles



SOURCE: CERI.

NOTE: No station costs included.

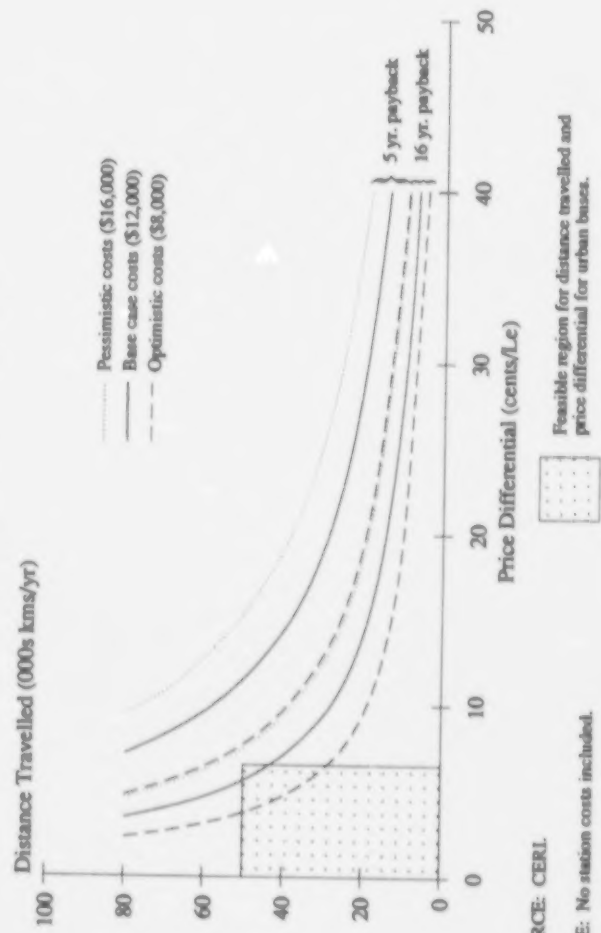
Figure G.3
Payback Based on Conversion Cost and
Price Spread for Heavy Vehicles



SOURCE: CERL

NOTE: No station costs included.

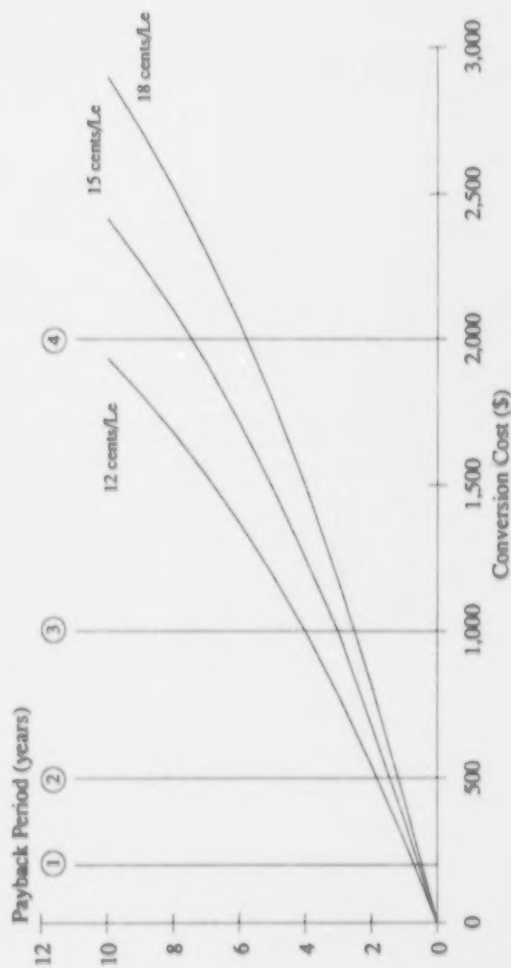
Figure G.4
Payback Based on Distance Travelled and
Price Spread for Urban Buses



SOURCE: CERL

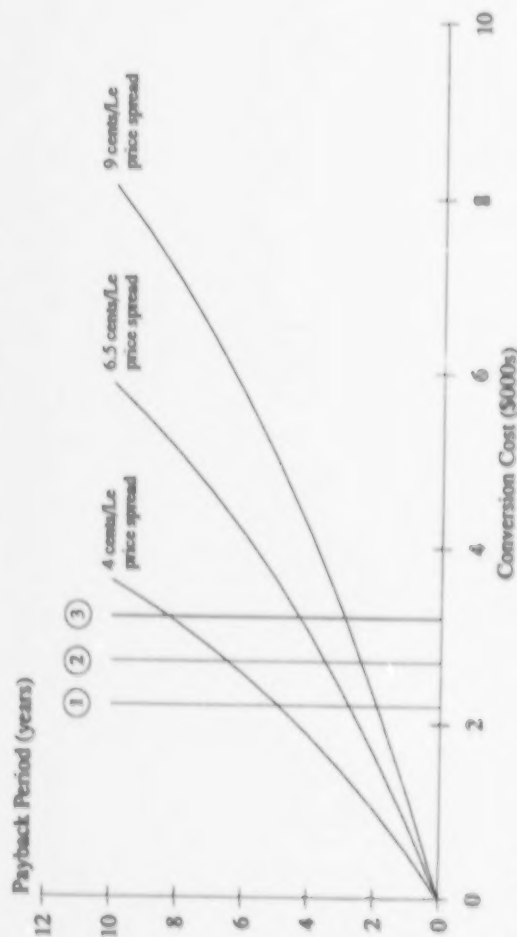
NOTE: No station costs included.

Figure G.5
Payback Based on Price Differential and
Conversion Cost for L/M Vehicles



- SOURCE: CERL
- 1 - OEM conversion cost (\$200).
 - 2 - Optimistic conversion cost (\$500).
 - 3 - Base case conversion cost (\$1,000).
 - 4 - Pessimistic conversion cost (\$2,000).

Figure G.6
Payback Based on Price Differential and
Conversion Cost for Heavy Vehicles

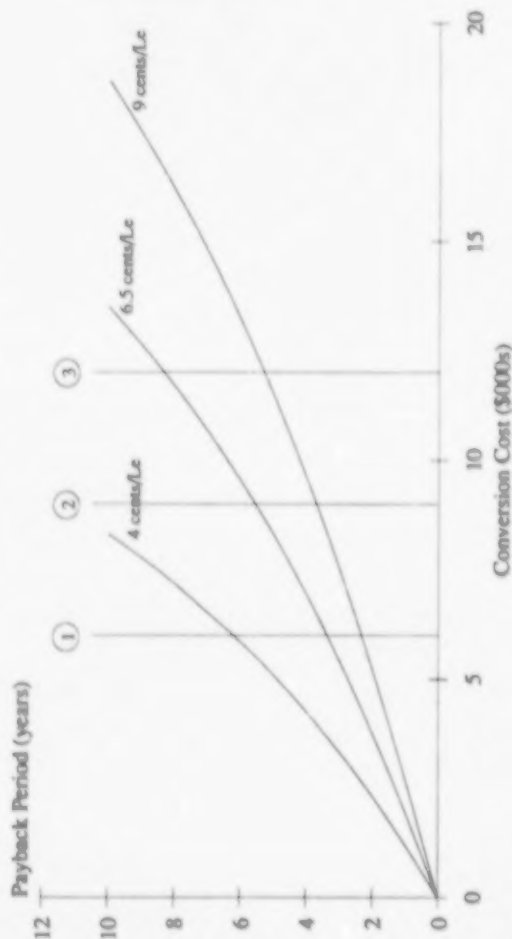


SOURCE: CERL

NOTE: Heavy vehicles weighing over 3855.6 kg.

- 1 - Optimistic conversion cost for heavy vehicles (\$2,200).
- 2 - Base case conversion cost for heavy vehicles (\$2,700).
- 3 - Pessimistic conversion cost for heavy vehicles (\$3,200).

Figure G.7
Payback Based on Price Differential and
Conversion Cost for Heavy Vehicles

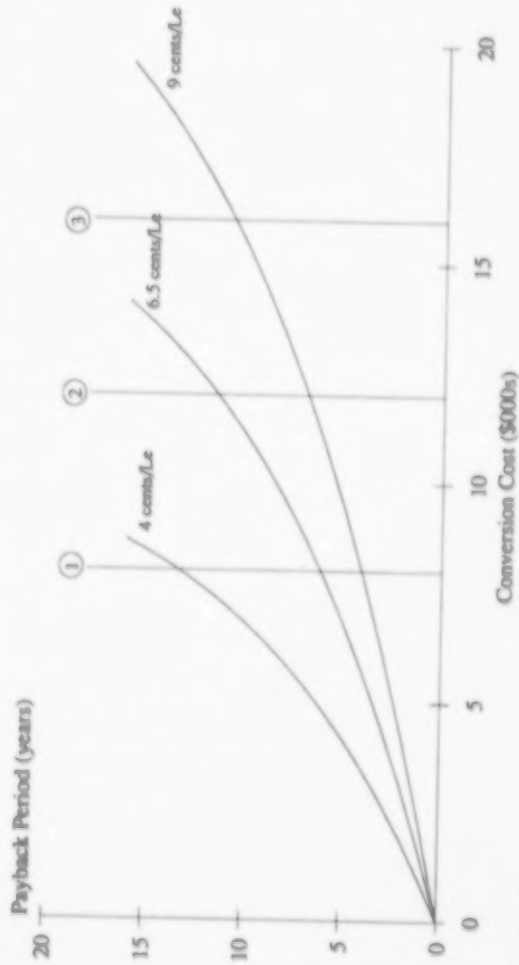


SOURCE: CERL

NOTE: Heavy vehicles weighing
 approximately 47000 kg.

- 1 - Optimistic conversion cost for heavy vehicles (\$6,000).
- 2 - Base case conversion cost for heavy vehicles (\$9,000).
- 3 - Pessimistic conversion cost for heavy vehicles (\$12,000).

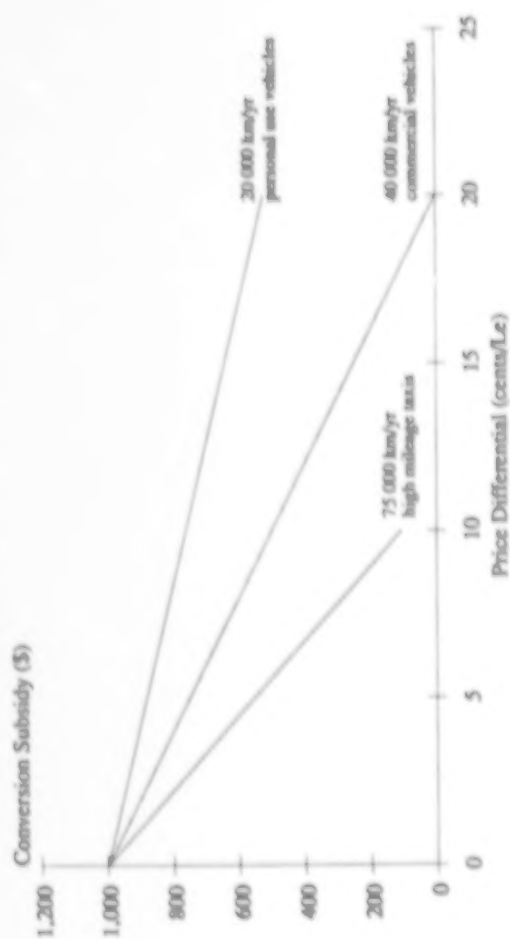
Figure G.8
Payback Based on Price Differential and
Conversion Cost for Urban Buses



SOURCE: CERL

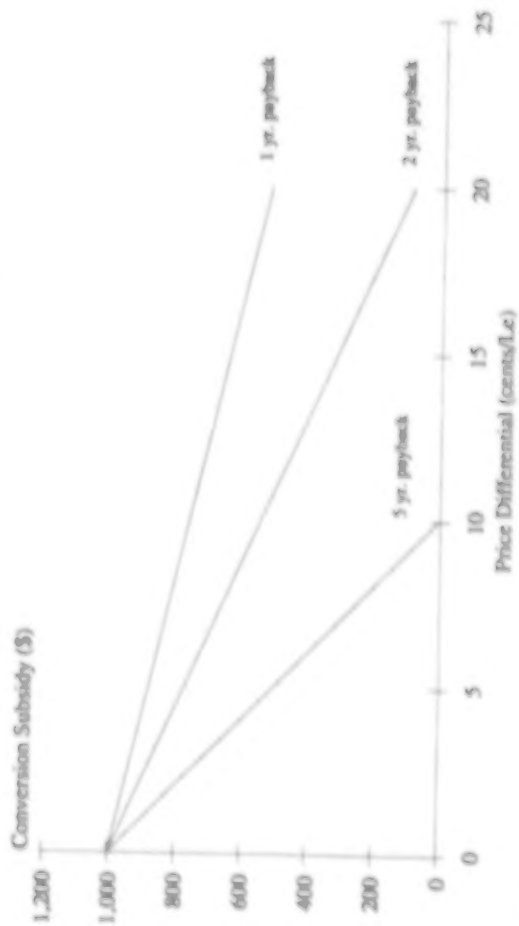
- 1 - Optimistic conversion cost for urban buses (\$8,000).
- 2 - Base case conversion cost for urban buses (\$12,000).
- 3 - Pessimistic conversion cost for urban buses (\$16,000).

Figure G.9
Light/Medium Methanol Conversion Subsidy
vs. Price Spread: One-Year Payback



SOURCE: CEBL

Figure G.10
Light/Medium Methanol Conversion
Required Subsidy vs. Price Spread



SOURCE: CERL

NOTE: Personal use vehicle.



Appendix H
ETHANOL SENSITIVITIES

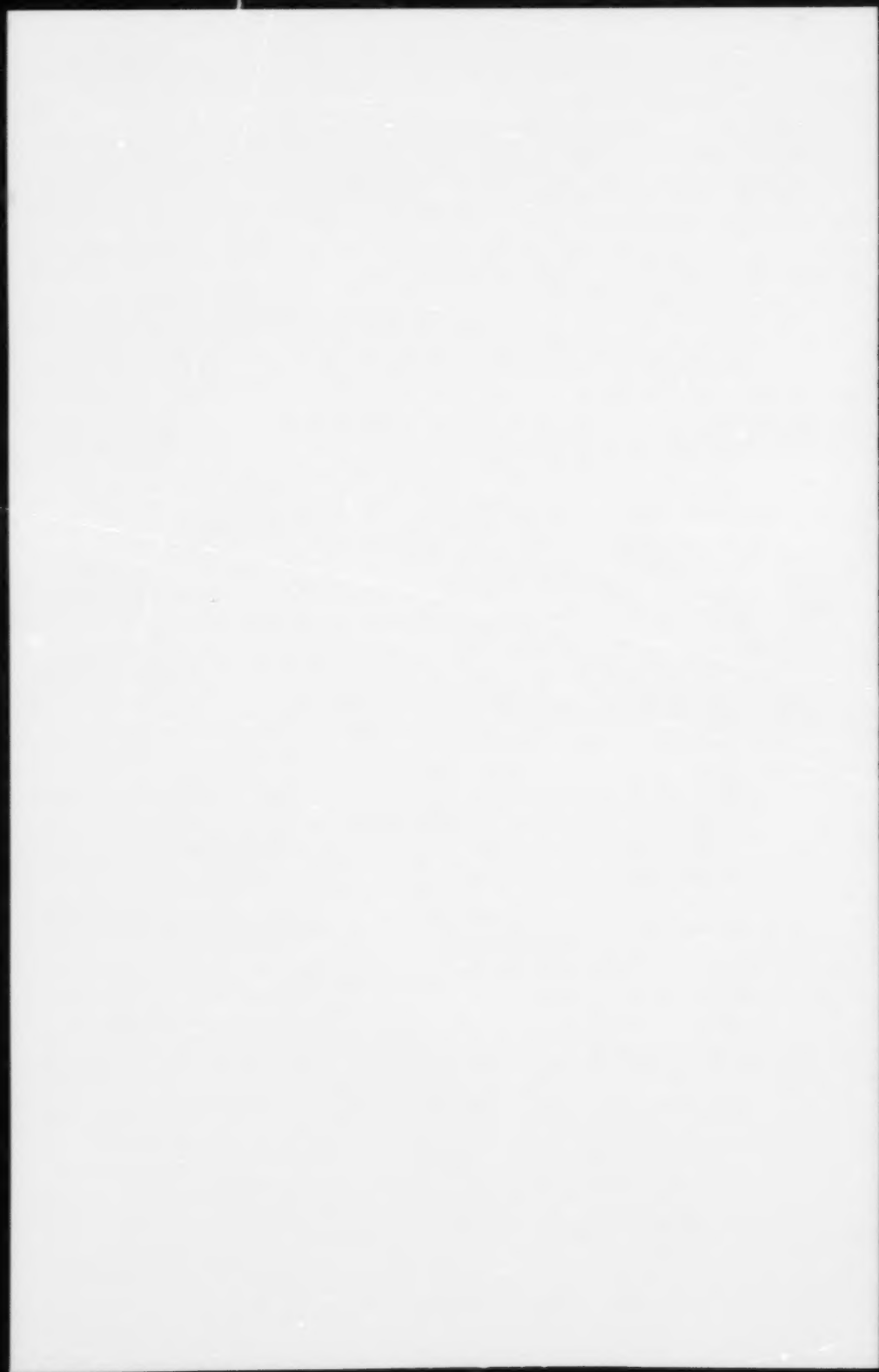
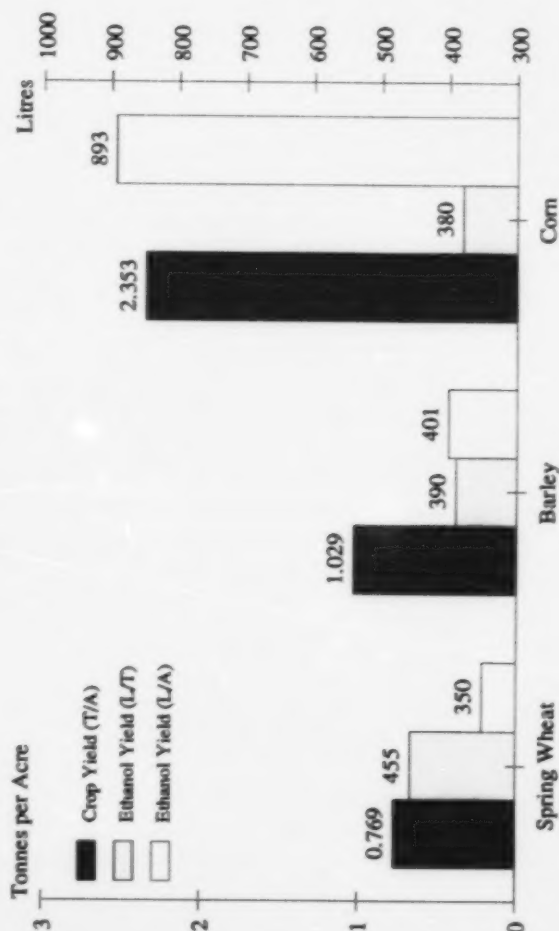


Figure H.1
Ethanol and Crop Yields



SOURCE: Canadian Grains Industry,
Statistical Handbook 87, CERL.

NOTE: Crop Yields represent Canadian
Average 1977 - 1987.

TABLE H.1
GRAIN PRICES
1977-1988
(\$Cdn)

Year	Corn ^a (Ont. & Que. Average)	Barley ^b (Alberta feed)	Wheat ^c (Winnipeg)
1977	86.67	79.00	103.80
1978	81.85	67.52	93.18
1979	107.22	73.95	110.18
1980	120.64	110.23	134.70
1981	151.91	124.01	167.86
1982	119.97	103.80	146.17
1983	114.72	91.40	132.30
1984	160.68	114.37	164.46
1985	140.91	120.34	158.68
1986	118.03	88.19	119.18
1987	93.36	61.55	90.26
1988	90.00	53.28 ^c	87.54
1989	135.16	99.89	139.30

SOURCES: (1) Ontario Corn Producers Association; (2) Alberta Grain Commission; (3) Winnipeg Commodity Exchange; and (4) Agriculture Canada.

^aCrop year average prices.

^bCalendar year average prices.

^cYear to April.

TABLE H.2
SENSITIVITY TO DDG PRICES
1988-1998
(10, 50, 100, 200 million litres/yr plants)

Case Description	10			50			100			200		
	Payout Year	1998 Rate of Return (%)		Payout Year	1998 Rate of Return (%)		Payout Year	1998 Rate of Return (%)		Payout Year	1998 Rate of Return (%)	
DDG Prices at \$280/Tonne												
Pessimistic	-	-	-	-	-	-	-	-	-	-	-	-
Mid-Range	-	-	-	-	-	-	1998	1	-	1998	5	-
Optimistic	1997	3	-	1993	14	-	1993	18	-	1992	21	-
DDG Prices at \$220/Tonne												
Pessimistic	-	-	-	-	-	-	-	-	-	-	-	-
Mid-Range	-	-	-	-	-	-	-	2	-	-	-	-
Optimistic	-	-	-	1995	7	-	1994	11	-	1993	14	-
Base Case - DDG Prices at \$170/Tonne												
Pessimistic	-	-	-	-	-	-	-	-	-	-	-	-
Mid-Range	-	-	-	-	-	-	-	-	-	-	-	-
Optimistic	-	-	-	-	-	-	1996	4	-	1995	7	-
DDG Prices at \$130/Tonne												
Pessimistic	-	-	-	-	-	-	-	-	-	-	-	-
Mid-Range	-	-	-	-	-	-	-	-	-	-	-	-
Optimistic	-	-	-	-	-	-	-	-	-	-	-	-
DDG Prices at \$110/Tonne												
Pessimistic	-	-	-	-	-	-	-	-	-	-	-	-
Mid-Range	-	-	-	-	-	-	-	-	-	-	-	-
Optimistic	-	-	-	-	-	-	-	-	-	1998	1	-

SOURCE: Canadian Energy Research Institute.

TABLE H.3
SENSITIVITY ON ETHANOL YIELD
PER TONNE OF FEEDSTOCK
1988-1998
(10, 50, 100, 200 million litres/yr plants)

Case Description	10		50		100		200	
	Payout Year	1998 Rate of Return (%)	Payout Year	1998 Rate of Return (%)	Payout Year	1998 Rate of Return (%)	Payout Year	1998 Rate of Return (%)
Ethanol Yield 400 Litres/Tonne								
Pessimistic	-	-	-	-	-	-	-	-
Mid-Range	-	-	-	-	-	-	-	-
Optimistic	-	-	1997	3	1995	7	1994	10
Base Case -								
Ethanol Yield 350 Litres/Tonne								
Pessimistic	-	-	-	-	-	-	-	-
Mid-Range	-	-	-	-	-	-	-	-
Optimistic	-	-	-	-	1996	4	1995	7
Ethanol Yield 300 Litres/Tonne								
Pessimistic	-	-	-	-	-	-	-	-
Mid-Range	-	-	-	-	-	-	-	-
Optimistic	-	-	-	-	-	-	1997	3

SOURCE: Canadian Energy Research Institute.

TABLE H.4
SENSITIVITY TO FEEDSTOCK COSTS
1988-1998
(10, 50, 100, 200 million litres/yr plants)

Case Description	10		50		100		200	
	Payout Year	1998 Rate of Return (%)	Payout Year	1998 Rate of Return (%)	Payout Year	1998 Rate of Return (%)	Payout Year	1998 Rate of Return (%)
Feed At \$85/Tonne								
Pessimistic	-	-	-	-	-	-	-	-
Mid-Range	-	-	-	-	-	-	1998	1
Optimistic	-	-	1994	10	1993	15	1993	18
Base Case - Feed At \$110/Tonne								
Pessimistic	-	-	-	-	-	-	-	-
Mid-Range	-	-	-	-	-	-	-	-
Optimistic	-	-	-	-	1996	4	1995	7
Feed At \$140/Tonne								
Pessimistic	-	-	-	-	-	-	-	-
Mid-Range	-	-	-	-	-	-	-	-
Optimistic	-	-	-	-	-	-	-	-

SOURCE: Canadian Energy Research Institute.



Appendix I***REGIONAL ALTERNATIVE FUEL
DEMAND ANALYSIS***



Appendix I

REGIONAL ALTERNATIVE FUEL DEMAND ANALYSIS

National motor gasoline consumption projected to have no growth after 1989. Fuel energy comparisons made on a volumetric/efficiency basis. Market penetration assumptions:

- E10 penetrates 1.5 percent of the regular unleaded market by 2000.
- E5P penetrates 1.5 percent of the premium unleaded market by 2000.
- NGV penetrates 3 percent of the diesel and 3 percent of the total gasoline market by 2000.
- Propane penetrates 2.5 percent of the diesel and 2.5 percent of the total gasoline market by 2000.
- M100 (methanol) penetrates 3.5 percent of the diesel market by 2000.
- M85 penetrates 3.5 percent of the unleaded market by 2000.

TABLE I.1
NATURAL GAS DEMAND BASED ON PENETRATION OF NGV BEING 0.3 PERCENT
OF THE DIESEL MARKET AND 0.3 PERCENT OF THE GASOLINE MARKET
IN 1990, GROWING TO 3 PERCENT AND 3 PERCENT BY 2000
(all volumes in thousands of litres)

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
ATLANTIC	147232.594	218984.571	290672.572	361823.799	433185.188	504295.380	576001.150	623640.746	671229.148	718767.272
QUEBEC	321418.944	472958.823	620884.745	764291.845	904623.060	1041009.475	1174910.627	1256745.157	1336079.020	1412906.297
ONTARIO	591178.361	887546.164	1109691.149	1495537.069	1808570.147	2126752.250	2454201.876	2684613.139	2919328.628	3158417.012
MANITOBA	71686.022	107315.842	141984.230	181056.515	219475.890	258602.878	299756.802	329304.555	359562.054	390530.794
SASK/NWT	96390.051	145035.796	195845.819	247764.062	302316.708	358437.005	418302.334	462512.738	508129.759	555146.513
ALBERTA	213966.967	315619.889	418359.069	519262.489	622411.977	724835.359	832647.180	906479.501	980808.093	1055592.762
BRITISH COLUMBIA	184011.954	272912.738	362930.497	452230.275	543429.266	634673.608	729709.139	795159.359	861225.878	927887.758
YUKON	4019.300	6252.026	8706.480	11343.935	14230.406	17326.227	20730.180	23476.280	26392.447	29481.546
CANADA	1629904.192	2426625.848	3231074.561	4033309.980	4848242.642	5665932.181	6506259.289	7081931.473	7662755.028	8248729.954

SOURCE: Canadian Energy Research Institute.

TABLE I.2

PROPANE DEMAND BASED ON PENETRATION OF PROPANE BEING 2 PERCENT
OF THE DIESEL MARKET AND 1.5 PERCENT OF THE GASOLINE MARKET
IN 1990, GROWING TO 2.5 PERCENT AND 2.5 PERCENT BY 2000
(all volumes in thousands of litres)

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
ATLANTIC	110795.945	115168.590	119853.743	124486.634	129265.806	134003.309	138892.538	143740.929	148548.538	153315.425
QUEBEC	236823.635	244355.744	252278.248	259849.990	267440.744	274687.533	281918.586	288781.781	295276.741	301403.085
ONTARIO	432545.802	455710.860	480754.087	506054.956	532535.014	559341.978	587405.820	615833.298	644628.802	673796.725
MANITOBA	54523.528	56937.478	59772.885	62612.111	65728.746	68880.680	72379.355	75948.910	79589.441	83301.043
SASK/NWT	74380.786	77824.397	81991.406	86205.557	90916.412	95727.294	101156.133	106747.013	112499.493	118413.132
ALBERTA	162800.010	167461.710	173603.256	179447.552	186230.622	192876.263	200853.963	208896.870	217002.413	225168.023
BRITISH COLUMBIA	140502.037	145259.093	151044.340	156692.531	162978.591	169218.038	176304.737	183451.403	190656.697	197919.281
YUKON	3196.579	3448.394	3735.611	4032.396	4357.614	4695.402	5068.546	5458.064	5864.140	6286.957
CANADA	1215568.323	1266166.265	1323033.575	1379381.727	1439453.549	1499430.496	1563979.678	1628858.268	1694066.266	1759603.671

SOURCE: Canadian Energy Research Institute.

TABLE I.3
METHANOL DEMAND BASED ON PENETRATION OF THE M85 BLEND
REPLACING .35 PERCENT OF TOTAL UNLEADED DEMAND
IN 1991, GROWING TO 3.5 PERCENT IN 2000
(all volumes in thousands of litres)

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
ATLANTIC	15610.806	30945.622	46004.448	60787.286	75294.133	89524.992	103479.861	117158.740	130561.631	143688.531
QUEBEC	38892.825	76223.070	111990.737	146195.824	178838.332	209918.261	239435.611	267390.382	293782.574	318612.187
ONTARIO	73708.475	147896.356	222563.643	297710.336	373336.436	449441.941	526026.853	603091.170	680634.894	758658.023
MANITOBA	6455.908	13097.635	19925.182	26938.549	34137.737	41522.744	49093.571	56850.217	64792.684	72920.971
SASK/NWT	7400.511	15399.534	23997.069	33193.116	42987.674	53380.745	64372.327	75962.420	88151.026	100938.143
ALBERTA	17693.759	36114.506	54662.239	73536.960	92738.667	112267.362	132123.043	152305.712	172815.367	193652.009
BRITISH COLUMBIA	15837.852	31897.481	48178.887	64682.068	81407.027	98353.761	115522.272	132912.560	150524.624	168358.464
YUKON	226.744	479.554	758.433	1063.378	1394.391	1751.471	2134.619	2543.834	2979.116	3440.465
CANADA	176026.879	352053.759	528080.638	704107.518	880134.397	1056161.277	1232188.156	1408215.036	1584241.915	1760268.795

SOURCE: Canadian Energy Research Institute.

TABLE I.4
METHANOL DEMAND BASED ON PENETRATION OF THE M100 BLEND
REPLACING 0.35 PERCENT OF DIESEL DEMAND
IN 1991, GROWING TO 3.5 PERCENT IN 2000
(all volumes in thousands of litres)

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
ATLANTIC	10775.767	21874.892	33297.925	45045.418	57117.921	69515.987	82240.165	95291.008	108669.065	122374.889
QUEBEC	18211.918	36864.699	55954.775	75478.579	95432.540	115813.092	136616.665	157839.692	179478.603	201529.830
ONTARIO	30301.541	62447.378	96478.892	132437.460	170364.462	210301.275	252289.280	296369.854	342584.376	390974.225
MANITOBA	5854.584	11898.960	18134.030	24560.695	31179.853	37992.407	44999.255	52201.300	59599.440	67194.578
SASK/NT	8994.936	18151.591	27465.817	36933.464	46550.384	56312.426	66215.444	76255.287	86427.807	96728.854
ALBERTA	17537.003	35010.599	52396.566	69670.686	86808.735	103786.494	120579.743	137164.259	153515.823	169610.213
BRITISH COLUMBIA	15601.091	31355.402	47250.314	63273.210	79411.472	95652.483	111983.626	128392.282	144865.835	161391.667
YUKON	475.006	1004.201	1589.310	2232.059	2934.172	3697.375	4523.394	5413.954	6370.781	7395.599
CANADA	107751.846	218607.722	332567.630	449631.569	569799.539	693071.540	819447.572	948927.635	1081511.730	1217199.855

SOURCE: Canadian Energy Research Institute.

TABLE I.5
ETHANOL DEMAND BASED ON PENETRATION OF THE E10 BLEND
REPLACING 0.3 PERCENT OF TOTAL UNLEADED DEMAND
IN 1991, GROWING TO 1.5 PERCENT IN 2000
(all volumes in thousands of litres)

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
ATLANTIC	957.217	1328.258	1692.529	2050.032	2400.765	2744.729	3172.568	3591.946	4002.863	4405.318
QUEBEC	2384.815	3271.671	4120.202	4930.407	5702.287	6435.842	7340.808	8197.868	9007.021	9768.267
ONTARIO	4519.627	6348.055	8188.241	10040.186	11903.889	13779.350	16127.352	18490.051	20867.449	23259.544
MANITOBA	395.861	562.181	733.059	908.494	1088.487	1273.037	1505.150	1742.959	1986.466	2235.669
SASK/NWT	453.782	660.984	882.866	1119.427	1370.668	1636.590	1973.578	2328.917	2702.605	3094.642
ALBERTA	1097.202	1550.118	2011.054	2480.010	2956.986	3441.982	4050.734	4669.510	5298.312	5937.138
BRITISH COLUMBIA	971.139	1369.114	1772.528	2181.382	2595.675	3015.408	3541.774	4074.939	4614.904	5161.668
YUKON	13.903	20.584	27.903	35.862	44.460	53.698	65.445	77.991	91.336	105.481
CANADA	10793.546	15110.964	19428.382	23745.800	28063.218	32380.637	37777.409	43174.182	48570.955	53967.728

SOURCE: Canadian Energy Research Institute.

TABLE I.6
 ETHANOL DEMAND BASED ON PENETRATION OF THE ESP BLEND
 REPLACING 0.3 PERCENT OF PREMIUM TOTAL UNLEADED DEMAND
 IN 1991, GROWING TO 1.5 PERCENT IN 2000
 (all volumes in thousands of litres)

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
ATLANTIC	74.212	103.743	133.180	162.544	191.814	220.995	257.445	293.786	330.017	366.139
QUEBEC	347.738	473.677	592.098	703.001	806.366	902.254	1019.738	1127.826	1226.515	1315.808
ONTARIO	455.560	647.016	843.747	1045.754	1253.036	1465.594	1732.939	2006.879	2287.413	2574.542
MANITOBA	16.943	24.126	31.542	39.189	47.069	55.181	65.394	75.897	86.690	97.773
SASK/NWT	23.740	34.907	47.028	60.105	74.136	89.123	108.154	128.379	149.798	172.410
ALBERTA	66.319	92.573	118.670	144.611	170.396	196.024	228.010	259.801	291.396	322.796
BRITISH COLUMBIA	120.162	170.484	222.096	274.997	329.189	384.671	454.426	525.793	598.773	673.366
YUKON	0.230	0.339	0.457	0.584	0.722	0.868	1.054	1.252	1.462	1.684
CANADA	1104.903	1546.865	1988.826	2430.787	2872.749	3314.710	3867.162	4419.613	4972.065	5524.516

SOURCE: Canadian Energy Research Institute.



COST REFERENCES*

(A) Conversion Cost References

	Natural Gas	Methanol	Propane
Light/Medium Vehicles	(1) 2,600 Cdn (2) 2,800 Cdn (3) 3,000 Cdn	(4) 500 US (4) 350 US (5) 1,500-2,200 US	(6) 900-1,600 US (7) 1,600-2,000 Cdn
Heavy Vehicles¹	(2) 2,800 Cdn (8) 2,700 US	(4) 3,200 US (5) 1,500-2,200 US	
Buses	(9) 35,936 Cdn (3) 30,000-50,000 Cdn (10) 35,000	(9) 11,076 Cdn (11) 13,000-19,000 Cdn	(12) 15,540 Aus

- (1) Canada, Department of Energy, Mines and Resources. *Natural Gas, An Alternative Transportation Fuel*. Cat. No. M27-71/1988. Ottawa, Ontario: Supply and Services Canada, 1988.
- (2) Ontario, Ministry of Transportation and Communications. *Switching to Natural Gas: A Guide to Successful Conversion*. Downsview, Ontario: Transportation Energy Management Program, March 1985.
- (3) *The Role of Energy Efficiency, Fuel Switching and Lifestyles Change in the Emissions Management of Nitrogen Oxides and Volatile Organic Compounds*. Energy Efficiency, Alternative Energy, Lifestyle Work Group, R. McKenzie, Chairman, March 1, 1990.
- (4) Moreno, Rene, Jr., and Bailey, D.G. Fallen. *Alternative Transport Fuels from Natural Gas*. Technical Paper Number 98. Industry and Energy Series. Washington, D.C.: Faber Industries SPA, June 1989.
- (5) United States, Department of Energy. *Assessment of Methane-Related Fuels for Automotive Fleet Vehicles, Volume 2*. Washington, D.C.: U.S. Department of Commerce, February 1982.
- (6) Sperling, Daniel. *New Transportation Fuels, A Strategic Approach to Technological Change*. Los Angeles, California and London, England: University of California Press, Berkeley, 1988.
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- (8) Moran, T.L., and Fiore, V.B. "R&D Opportunities to Enhance the Utilization of Natural Gas as a Vehicle Fuel." Conference Paper from Gaseous Fuels for Transportation I, Vancouver, British Columbia, Canada, August 7-10, 1986.
- (9) Canada. Department of Energy, Mines and Resources. Canada Centre for Mineral and Energy Technology. *Cost-Effectiveness of Alternative Transportation Fuels in Urban Bus Operations*. Prepared for the Efficiency and Alternative Energy Technology Branch, Energy, Mines and Resources Canada (scientific authority: Russ Robinson). Ottawa, Ontario: SYPHER:MUELLER International Inc., November 1989.
- (10) Bob Cummings, Canadian Gas Association
- (11) Peter Bigwood, Ontario Bus Industries
- (12) Noon, A. "A Bus Operator's Experience in the Conversion of Horizontal Diesel Engines to Operate on Both CNG and LPG." Conference paper from Gaseous Fuels for Transportation I, Vancouver, British Columbia, August 7-10, 1986.

(B) Station Cost References

Natural Gas	Methanol	Propane
(1) 225,000-396,000 US	(4) 99,700-149,700 US	(6) 40,000 US
(2) 250,000-300,000 Cdn	(5) 195,000 US	(7) 30,000 Cdn
(3) 175,000-193,000 US		

- (1) United States. Environment Protection Agency. *Analysis of the Economic and Environmental Effects of Compressed Natural Gas as a Vehicle Fuel. Volume 2, Heavy-Duty Vehicles*. Special Report. Ann Arbor, Michigan: Office of Mobile Sources, April 1990.
- (2) Heenan, John S. "Advanced NGV Refuelling Systems in Canada." Paper 15 in NGV-88: "NGV - The New Direction in Transportation," October 29, 1988.
- (3) United States. Environment Protection Agency. *Analysis of the Economic and Environmental Effects of Compressed Natural Gas as a Vehicle Fuel. Volume 1, Passenger Cars and Light Trucks*. Special Report. Ann Arbor, Michigan: Office of Mobile Sources, April 1990.
- (4) J.E. Sinor Consultants Inc. *The Clean Fuel Report*. Vol. 1, No. 2. Niwot, Colorado: J.E. Simon Consultants Inc., February 1990.

- (5) Canada. Department of Energy, Mines and Resources. Canada Centre for Mineral and Energy Technology. *Cost-Effectiveness of Alternative Transportation Fuels in Urban Bus Operations*. Prepared for the Efficiency and Alternative Energy Technology Branch, Energy, Mines and Resources Canada (scientific authority: Russ Robinson). Ottawa, Ontario: SYPHER:MUELLER International Inc., November 1989.
- (6) Moreno, Rene, Jr. and Bailey, D.G. Fallen. *Alternative Transport Fuels from Natural Gas*. Technical Paper No. 98. Industry and Energy Series. Washington, D.C.: Faber Industries SPA, June 1989.
- (7) Propane Gas Association of Canada Inc. *Auto Propane in Alberta*. Calgary, Alberta: Propane Gas Association of Canada Inc., February 1990.

(C) Other References

- (1) OEM methanol conversion cost (L/M) \$50-200 US

SAE International. *Fuel Methanol, A Decade of Progress*. PT-36. Edited by Norman D. Brinkman, E. Eugene Eckland and Roberta J. Nichols. Warrendale, Pennsylvania: Society of Automotive Engineers, Inc., 1990.

- (2) OEM propane conversion cost (L/M) \$600-1000 US

Delmas, P. "The Supply, Demand, and Pricing of Natural Gas for Motor Vehicle Use in Canada." Conference paper for Gaseous Fuels for Transportation I, Vancouver, British Columbia, August 7-10, 1986.

- (3) Average distance travelled by an urban bus = 50 244 km/yr.
Fuel consumption of an urban bus: 532.2 L/1000 km.

Canada. Department of Energy, Mines and Resources. Canada Centre for Mineral and Energy Technology. *Cost-Effectiveness of Alternative Transportation Fuels in Urban Bus Operations*. Prepared for the Efficiency and Alternative Energy Technology Branch, Energy, Mines and Resources Canada (scientific authority: Russ Robinson). Ottawa, Ontario: SYPHER:MUELLER International Inc., November 1989.

Statistics Canada: Fuel efficiency of personal vehicles: average 123.44 L/1000 km

Heavy Vehicles¹ = those > 3855.6 kg.

* For a Complete List of References, see Bibliography.



GLOSSARY

- AFTER-MARKET CONVERSION (RETROFIT):** Installation of equipment for burning a different type of fuel in a vehicle after initial construction is completed.
- AIR-FUEL MIXTURE:** Air and fuel supplied to an engine which, when burned together, expand and provide propulsion.
- AIR-FUEL RATIO:** Ratio of the weight of air to fuel that is required for consistent ignition in a vehicle engine.
- ALCOHOL:** One of a large series of organic compounds; some occur naturally but most are manufactured. Formed by replacing one or more hydrogen atoms in a hydrocarbon molecule with a hydroxyl group.
- ALCOHOL CONTAINING FUEL:** Fuel containing 1-100 vol% alcohol, (i.e., blend fuels as well as fuel alcohols).
- ALDEHYDE:** One of a series of chemical compounds, many toxic, formed by incomplete oxidation of alcohols (e.g., formaldehyde is made from methanol).
- ANTIKNOCK:** Resistance of motor fuel to the tendency to knock (see Knocking).
- AROMATICS:** Hydrocarbons characterized by unsaturated ring structures of carbon atoms. Commercial petroleum aromatics are benzene, toluene and xylene (BTX).
- BIOMASS:** Material of plant origin, including agricultural wastes, wood and animal manure.
- BLEND FUEL:** Fuel containing blend of gasoline and 1-60 percent alcohol.
- BOILING POINT:** Temperature at which a substance changes from a liquid to a vapour and vice versa at a specified pressure.
- BUTANE:** Highly flammable, volatile, gaseous hydrocarbon (C_4H_{10}) that is extracted from natural gas or produced by cracking petroleum. Used as a blending compound to increase the vapour pressure of gasoline and promote cold starting. Exists in two different molecular forms or isomers; in normal butane (n-butane), the four carbon atoms are arranged in a straight line, but in isobutane they form a branched chain. The calorific value of n-butane is higher.

CARBON MONOXIDE: A colourless, odourless, toxic gas composed of equal parts of carbon and oxygen. Produced by partial combustion (oxidation) of hydrocarbon fuels.

CARBURETOR: Component of a vehicle engine that automatically prepares and supplies to the cylinder the correct mixture of fuel vapour and air for efficient combustion.

CATALYST: A substance that helps to initiate a chemical reaction and enables it to proceed under less severe conditions (for example, at a lower temperature or pressure), but remains unchanged itself.

CATALYTIC CONVERTER: A device fitted to the exhaust system of a motor vehicle to reduce the levels of hydrocarbons, carbon monoxide and nitrogen oxides in the exhaust gas. Various metals and alloys, including platinum, copper and nickel, can be used. Since tetraethyl lead poisons the catalyst, lead-free gasoline must be used.

CATALYTIC REFORMING: A refining process using controlled heat and pressure with catalysts to rearrange certain hydrocarbon molecules, thereby converting paraffinic and naphthenic type hydrocarbons (e.g., low-octane gasoline boiling range fractions) into petrochemical feedstocks and higher octane stocks suitable for blending into finished gasoline. Catalytic reforming is reported in two categories. They are:

Low Pressure: A processing unit operating at less than 225 pounds per square inch gauge (PSIG) measured at the outlet separator.

High Pressure: A processing unit operating at either equal to or greater than 225 pounds per square inch gauge (PSIG) measured at the outlet separator.

CELLULOSE: Complex fibrous carbohydrate that performs a supporting function in plant tissue. Molecule consists of glucose units linked together in chains, with the formula $(C_6H_{10}O_5)_n$, where $n = 2000$ to 4000 . The most abundant naturally occurring organic compound. Can be broken down by hydrolysis into simpler carbohydrates like starches and sugars.

COMPRESSION RATIO: Ratio of the volume of gas within the cylinder of a vehicle engine before compression to the volume after the gas has been fully compressed by the piston. If the compression ratio is too high, knocking occurs. In a modern automobile engine, the compression ratio is about 9:1.

CONVENTIONAL FUELS: Liquid hydrocarbon fuels obtained by refining crude oil.

- CORROSION:** Erosion of a metal surface caused by chemical reaction of the metal with substances in contact with it.
- COSOLVENT:** Chemical compound with good solvent properties that is added to a methanol-gasoline blend to prevent phase separation, reduce corrosion and improve lubrication.
- CRUDE OIL:** Raw petroleum in its naturally occurring state which can be recovered at a commercial rate through a well. Consists of a mixture of many different hydrocarbons with traces of impurities, differing in composition according to location.
- CYLINDER:** Engine component consisting of a metal tube containing a piston, piston rod and end seals and fitted with valves to allow entrance of fuel mixture and exit of burned gases.
- DEDICATED CARBURETION SYSTEM:** A vehicle system that can be operated on one fuel only. Opposite of a dual-fuel system.
- DIESEL FUEL:** High-grade fuel oil suitable for use in compression ignition engines. Available in different grades; regular has a cetane number of 40-45 and premium of 45-50.
- DISTILLATION:** Process of heating a liquid to the boiling point and collecting and condensing the resulting vapour.
- DUAL-FUEL CARBURETION SYSTEM:** A vehicle system equipped to operate on two different fuels, (e.g., diesel and methanol).
- ENZYME:** Type of protein found in living matter; acts as a catalyst in chemical reactions occurring within the cells. Each enzyme is specific to a particular reaction.
- ETHANOL:** Colourless, volatile, flammable liquid with the formula C_2H_5OH . Used as a fuel, as a reagent in many industrial processes, and in intoxicating beverages.
- FERMENTATION:** Breakdown of a sugar into ethanol and carbon dioxide by the action of yeasts or bacteria.
- FLAME SPEED:** The rate at which combustion moves through an explosive mixture such as a fuel.
- FLARE:** To burn off excess natural gas at the wellhead.
- FUEL ALCOHOL/FUEL METHANOL/FUEL ETHANOL:** Fuel containing minimum 85 vol% alcohol/methanol/ethanol, (e.g., M85, M100). "Fuel alcohol" is sometimes referred to as "alcohol fuel".
- FUEL FILTER:** Device installed in the fuel line of a vehicle between the fuel pump and the carburetor to remove solid particles and water.

FUEL INJECTOR: High-pressure pump that injects liquid fuel directly into the engine cylinder.

GASIFICATION: Production of methane from coal or biomass by heating the feedstock to high temperatures under high pressure in a restricted amount of oxygen.

GASOHOL: A blend of 10 percent ethanol with gasoline.

GASOLINE: Refined mixture of volatile, petroleum-derived hydrocarbon liquids with octane numbers ranging from 60 to above 100; used as a fuel for spark-ignition engines.

HEATING VALUE: Amount of heat released during complete oxidation (combustion) of a given amount of a fuel at constant pressure. Also called heat of combustion.

HIGH-LEVEL BLEND: Fuel for purpose-built or retrofitted cars and containing 10-60 vol% alcohol (e.g., E20).

HYDROCARBON: One of a very large series of chemical compounds, consisting solely of carbon and hydrogen atoms, which form the basis of all petroleum products. Those with few carbon atoms are gases and those with many are solids.

HYDROGEN SULPHIDE: Flammable, toxic gas with a characteristic odour of rotten eggs. Formed by reaction of hydrogen with sulphur compounds during petroleum refining and occurs naturally in raw natural gas. Causes metals to corrode.

HYDROLYSIS: Chemical reaction of water with another compound; the molecules of both are split, the two parts of the water molecule each combining with part of the molecule from the other compound.

IGNITION POINT: The lowest temperature at which combustion begins and is maintained in a fuel when it is heated in air.

ISOPROPANOL: Colourless liquid in the alcohol series, with the formula $(\text{CH}_3)_2\text{CHOH}$, commonly used as a cosolvent in methanol-gasoline blends.

ISOBUTANOL: A four-carbon alcohol often used as a cosolvent in methanol-gasoline blends.

ISOMERIZATION: A refining process which alters the fundamental arrangement of atoms in the molecule without adding or removing anything from the original material. Used to convert normal butane into isobutane, (C4), an alkylation process feedstock, and normal pentane and hexane into isopentane, (C5), and isohexane, (C6), high-octane gasoline components.

- KNOCKING:** Pinging sound in a spark-ignition engine caused by the fuel-air mixture self-igniting before the spark is passed at the spark-plug; can lead to engine damage. Prevented by using a higher octane fuel.
- LEADED GASOLINE:** Gasoline containing a small quantity of tetraethyl or tetramethyl lead to raise the octane number, thereby increasing the antiknock quality of the fuel.
- LIGNIN:** Organic compound that supports plant tissue. Wood is 25 to 35 percent lignin. Binds cellulose fibres together and therefore interferes with the breakdown of cellulose into sugars during hydrolysis.
- LIQUEFACTION:** Conversion of a solid feedstock to a liquid fuel by the application of heat, or of a gas to a liquid fuel by the use of cold or pressure.
- LIQUEFIED PETROLEUM GAS (LPG):** A group of hydrocarbon gases, primarily butane and propane, obtained from crude oil and natural gas production and also as by-products of refining. Compressed to liquid form for storage and transportation and used as a fuel.
- LOW-LEVEL BLEND:** Fuel usable in existing cars and containing a maximum 10 vol% alcohol (e.g., M3, E10).
- METHANE:** Colourless, odourless, flammable gas with the formula CH_4 , making it the simplest hydrocarbon. Main constituent of natural gas.
- METHANOL:** Colourless, toxic liquid with the formula CH_3OH ; the simplest of the alcohol series. Also called methyl alcohol.
- METHYL TERTIARY BUTYL ETHER:** Liquid additive used to increase the octane number of unleaded gasoline.
- NATURAL GAS:** Flammable mixture of gaseous hydrocarbons, mainly methane. Occurs naturally, usually in association with crude oil.
- NITROGEN OXIDES:** Various gaseous combinations of nitrogen and oxygen atoms produced by burning fuels and therefore found in exhaust emissions. Usually abbreviated as NO_x . All are toxic except nitrogen dioxide.
- OCTANE:** Flammable, petroleum-derived hydrocarbon (C_8H_{18}) that exists in many molecular forms or isomers.
- OCTANE ENHANCER:** Additive that raises the octane number of a fuel.
- OCTANE NUMBER:** An arbitrary value that indicates the antiknock quality, or grade, of a gasoline, (i.e., provides a measure of

the resistance of the fuel to premature ignition). Iso-octane (octane number 100) is added to n-heptane (octane number 0) to produce a mixture with the same knocking characteristics as the gasoline blend being tested. The proportion of iso-octane in the mixture indicates the octane number of the gasoline blend. Available gasoline blends usually range in octane number from 92 to 100.

OCTANE RATING: See Octane Number.

OLEFIN: One of a group of manufactured hydrocarbons that are characterized chemically by a double bond between two hydrogen atoms, making them very reactive and therefore useful industrially. Ethylene and propylene belong to this group.

OXYGENATES: Oxygenates include both alcohols and ethers used as octane boosting additives for gasoline (e.g., ethanol, methyl tertiary butyl ether). When these compounds are added to gasoline in small amounts, a blend known as "oxygenated gasoline" results.

PROPANE: Heavy, volatile, colourless hydrocarbon gas (C_3H_8) that can be readily liquefied at ambient temperatures and is the main component of LPGs. Can be extracted from natural gas and is also produced during crude oil refining.

REFINERY BLENDING: Mixing of an alcohol fuel with gasoline at the refinery for distribution as a blended fuel.

REFINING: Process of heating crude oil until it separates into its chemical components, which are then processed into usable products.

SOUR GAS: Natural gas with a relatively high proportion of sulphur, giving it an unpleasant odour.

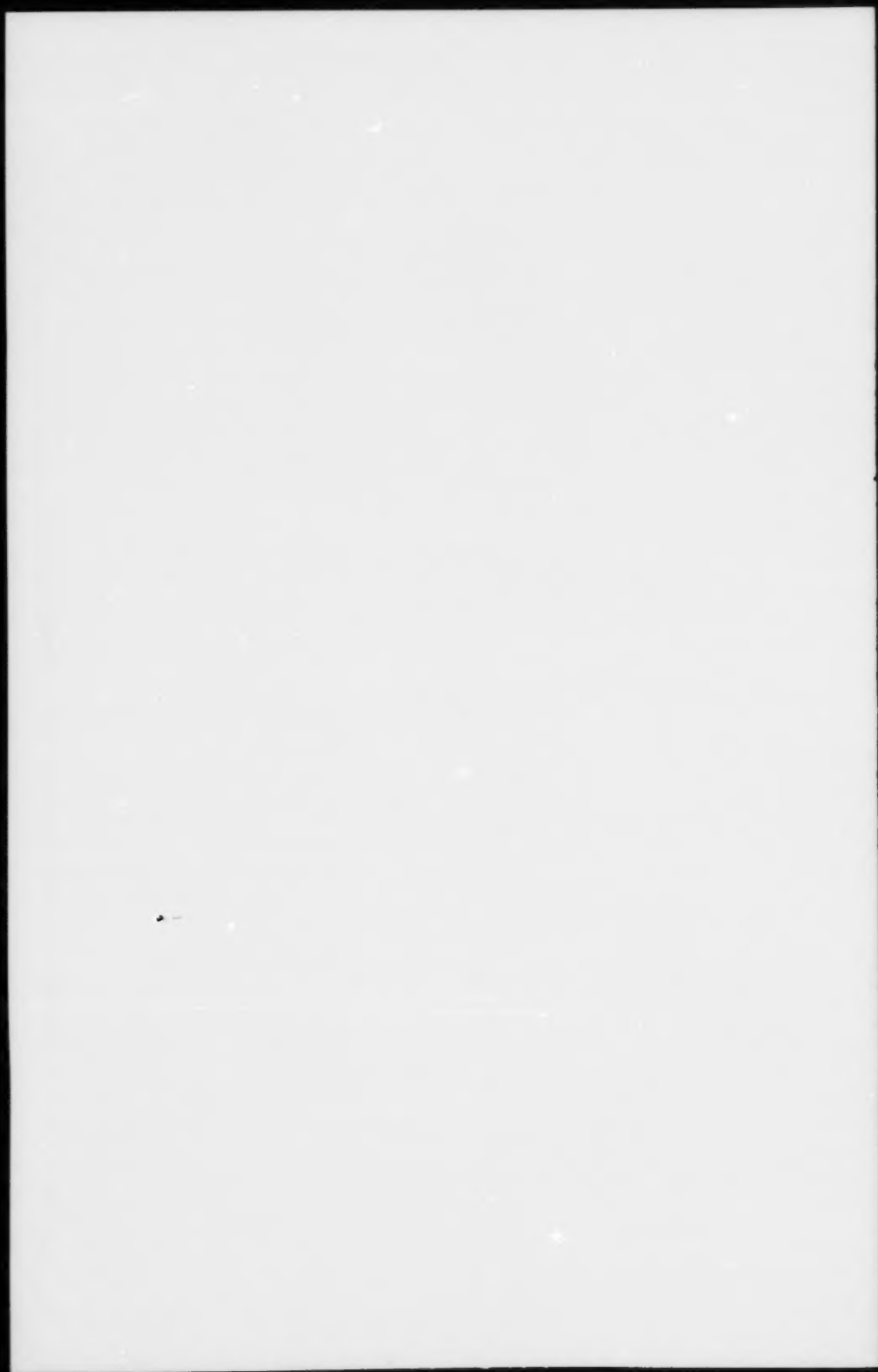
SPARK-ADVANCE CURVE: Curve indicating the instant at which a spark-ignition engine should fire for most efficient operation throughout the range of speed and operating conditions. The spark is automatically retarded or advanced according to requirements. To obtain maximum power at higher speeds, it is necessary for the spark to occur slightly earlier in the engine cycle.

SPARK-IGNITION ENGINE: A piston engine that relies on a spark-plug within each engine cylinder to ignite the fuels. Gasoline-powered engines are of this type.

SPARK-PLUG: Device fitted onto the cylinder of a spark-ignition engine that contains a pair of electrodes between which a spark passes to ignite the fuel.

- STARCH:** A white, odourless, tasteless, granular carbohydrate ($C_6H_{10}O_5$) that is the chief storage form of carbohydrates in plants. It can be broken down fairly readily by enzymes or acids to produce fermentable sugars for ethanol production.
- STEAM REFORMING:** Production of synthesis gas by passing methane or other hydrocarbon vapour over a catalyst at high temperature.
- STOICHIOMETRIC RATIO:** Ideal air-fuel mixture for an engine (i.e., the fuel is completely oxidized and no excess air remains).
- STRIPPER COLUMN:** Pressure vessel for purifying methanol by removing carbon dioxide and heavy hydrocarbons.
- SUGAR:** Simple type of carbohydrate found in plants. Can be directly fermented to produce ethanol.
- SURFACTANT:** Liquid added to an emulsion to ensure that the liquids do not separate out.
- TERTIARY BUTANOL:** Type of alcohol commonly used as a cosolvent in methanol-gasoline blends.
- UNLEADED GASOLINE:** Gasoline blend containing sufficient high-octane hydrocarbons to ensure a high octane number without the use of lead additives.
- VAPORIZER:** Device for converting liquid fuel into a gas.
- VAPOUR PRESSURE:** The amount of pressure required to prevent a liquid from vaporizing in a confined space.
- VOLATILE:** Readily evaporates at relatively low temperatures.
- VOLATILITY:** Measure of the tendency of a fuel to change from a liquid to a vapour at a specified temperature and pressure.
- XYLENE:** An aromatic hydrocarbon, ($C_6H_4Y(CH_3)_2$), produced in petroleum refining (cracking) processes. One important use is as a solvent in the manufacture of paints. Along with toluene, it is a key ingredient in unleaded gasoline.

SOURCES: (1) *Alcohol and Alcohol Blends as Motor Fuels*, Vol. I. Prepared by The Swedish Motor Fuel Technology Co. (SDAB) for the International Energy Agency, (Stockholm 1986); (2) *Petroleum Supply Monthly* published by the U.S. Energy Information Administration, Washington, D.C., Nov. 1987; (3) *Future Transportation Fuels, Alcohol Fuels*, Ministry of Supply and Services Canada, 1986; (4) *Future Transportation Fuels, Gaseous Fuels*, Ministry of Supply and Services Canada, 1986; and (5) *Future Transportation Fuels, Conventional Fuels*, Ministry of Supply and Services Canada, 1986.



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